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SECOND REPORT ON THE STRONG-MOTION INSTRUMENTATION PROGRAM

1976

CALIFORNIA DIVISION OF MINES AND GEOLOGY

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SECOND REPORT ON THE STRONG-MOTION INSTRUMENTATION PROGRAM

Prepared under the direction of

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April 1, 1976

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SUMMARY

The State of California Strong Motion Instrumentation Program (SMIP) was established in Chapter 1152 of the Statutes of 1971 and the California Division of Mines and Geology (CDMG) was designated the responsible managing agency. The objective of the program is to obtain detailed records of the ground response motion of representative soil and rock units during earthquakes, and on the response behavior of all types of structures to those earthquake-generated ground motions. The earthquake motion data recorded by the instruments are reduced to a usable form by the U.S. Geological Survey Earthquake Engineering Branch as a part of its nationwide strong motion program responsibility, and analyzed through a computer complex located in Berkeley, California. The processed results are made immediately available to structural engineers for application to improvement of structure design for resistance to earthquake damage, thereby improving public safety and reducing property losses.

Funding of the Strong Motion Instrumentation Program is provided by an assessment of 7 cents per 1,000 dollars of estimated construction cost on building permits issued by cities and counties. The revenue from the assessment has averaged about $415,000 per year over the first three-plus years of operation and the FY 1975-76 revenue is estimated at $430,000, which amount is used as a base for program projection.

This report reviews CDMG's three years of management of the SMIP. It shows plans for completing instrument installation about the year 2035, and shows the program's gradual phasing from mainly instrument procurement and installation to entirely instrument maintenance. The present program plan was developed by the CDMG with guidance from the SMIP Advisory Board, in response to an adopted recommendation by the Legislative Analyst.

The program plan calls for the deployment of a total of 1,864 instruments and instrument systems over a 60-year period at a total cost of about $12,000,000. The completed network is to consist of 520 unitized instruments on "free-field" soil and rock sites including down-hole arrays; 400 instrument systems in selected buildings; and 944 unitized instruments on dams, bridges, and various utility structures.

Average installed costs of instrumentation are about $2,500 for each "free-field" or other unitized installation, $8,500 for each building system, and $20,000 for each three-sensor down-hole array. Periodic maintenance and record collection costs, on a basis of 150 instruments per technician, average about $220 per year for unitized instruments and instrument systems.

As the number of installed instruments increases over the years, the number of technicians required to perform maintenance functions will increase proportionately. These steadily increasing salary and related operating expense costs for maintenance are to be paid from the limited annual income, leaving a steadily diminishing balance to be applied to instrument procurement and installation, resulting in gradual slowing of the completion rate of the instrumentation phase.

In approximately the year 2035, the 1,864 planned instruments will be installed and operational, and instrument procurement will cease except for possible replacement. From that time, the 12 technicians, maintaining 150 instruments each, and a program manager will constitute the entire SMIP program. Their salaries and related operating expenses will require about $390,000, or 90 percent of the projected $430,000 annual revenue. The remaining $40,000 may be utilized to provide a reserve for post-earthquake evaluation and installation improvement. This surplus income may also be a factor in consideration of a reduction in the fee assessment. During the continuing stable maintenance phase of the program, the support, other than for direct maintenance, will be minimal and can be supplied on an "as-needed" basis from other CDMG programs.

PREFACE

This report in an earlier form was submitted to the California Legislature in response to the recommendation by the Legislative Analyst, and resolution by the Legislature, that the Division of Mines and Geology report on its overall plan for the Strong Motion Instrumentation Program. The report presents the need for the program by the structural engineering profession to advance the state of the art of designing and building earthquake-resistant structures. These improvements are needed to increase the safety of the occupants, and for all the people of California who must ultimately bear the costs of life and property loss due to inadequate earthquake-resistant design.

This report also includes the long-range plan for the implementation and operation of the program, the rationale for priority development, funding levels, and instrumentation objectives. It also addresses the place of the program in the multi-agency, nationwide instrumentation system and coordination with other agencies.

This report was prepared by Tom M. Wootton, geologist and program manager, William M. Wells, geophysicist, and Jay H. Power, geologist—all of the Division of Mines and Geology—from materials provided by Dr. H. Bolton Seed, Chairman of the Strong Motion Instrumentation Program Advisory Board, with the assistance of Dr. R. B. Matthiesen, of the U.S. Geological Survey and a member of the Advisory Board.

Appreciation is expressed to the authors of the appendices: R. B. Matthiesen, U.S. Geological Survey (Appendix D); Christopher Rojahn, U.S. Geological Survey and Chairman of the Subcommittee on Instrumentation for Structures (Appendix E); and C. J. Cortright, California Department of Water Resources, representing the California Water and Power Earthquake Engineering Forum (Appendix G). Thanks are also extended to C. Martin Duke, Donald E. Hudson, Laurence B. James, William B. Joyner, John F. Meehan, and Gordon B. Oakeshott for thoughtful review and helpful comments on the manuscript.

SECOND REPORT ON THE STRONG-MOTION INSTRUMENTATION PROGRAM

by the
California Division of Mines and Geology

INTRODUCTION

Justification for the Program

The largest losses of life and property in California due to geologic hazards have been caused by violent ground shaking during earthquakes (Alfors, and others, 1973, p. 19). One of the primary problems confronting structural engineers in their efforts to design earthquake-resistant structures with a maximum of safety and economy for the people of the State is the lack of knowledge of the forces and deformation induced in structures and facilities by potentially damaging motions of the ground upon which they are built. These forces and deformations are determined by the intensity and nature of shaking produced by earthquakes and the response of structures to them. Progress in improving earthquake-resistant design has been severely handicapped by the small number of quantitative records of strong earthquake-induced ground motions. These vary widely from site to site depending on such factors as magnitude of the earthquake, proximity of the site of these structures to the earthquake epicenter, local soil or rock conditions at the site, mechanism of faulting which produced the energy release, and the geology of the region through which the earthquake waves had to travel. Similarly, the response of structures to earthquake shaking varies with such factors as the type of structure, the height and extent of the structure, the characteristics of the material of which it is constructed, and the natural foundation materials on which the structure is placed.

Further, progress in developing a better understanding of the details of earthquakes by seismologists and geologists, including advances in the technology of earthquake prediction, regional planning, and the applicability of information obtained in one region for use in another, is seriously hampered by the lack of quantitative records of strong earthquake-induced ground motions.

Thus, it is not surprising that engineers, seismologists and geologists throughout the world are united in their belief that many more records of earthquake-induced ground and structure motions than now exist will be required to develop a comprehensive earthquake protection program. Such an improved program is necessary to ensure an adequate degree of public safety against this particular hazard with a maximum economy of design and construction. This has been a primary recommendation of virtually all major studies of earthquake hazard reduction programs in recent years. For example, in a study made for the Office of Science and Technology of the Executive Office of the President of the United States (Steinbrugge and others, 1970, p. 28-29), the following statement is made:

"For several decades the United States has had strong motion seismographs distributed in the more highly seismic parts of the country. This has been an important and meritorious program but for a variety of reasons it has not produced nearly the needed amount of data. The set is so limited there is some question as to its relevance in particular cases - for example to that part of the United States east of the Rocky Mountains. There have not been enough strong motion instruments in operation; and as a consequence they have not always been at the right place at the right time. Not only should the number of existing installations be multiplied by a factor of at least 100, but the instruments should be completely modernized taking full advantage of present day technology."

That report concluded that:

"Greatly increased effort must be devoted to the intelligent placement of strong motion seismic equipment, the collection of their records after destructive earthquakes, analyzing the motions to derive various engineering characteristics and making the original data and analyses available shortly after the earthquake. The fundamental aspect of all dynamic research in earthquake engineering is the ground motion to which the structure is subjected in a major earthquake. Without this data, all following research is based on assumption."

Along the same lines, the National Academy of Sciences Committee on the Alaska Earthquake (1969) in its report concluded:

"Increased effort should be devoted to collecting data on ground movements and associated physical changes both between and during strong earthquakes.

"Because there was no instrumented record of strong ground shaking during the Alaska earthquake, studies of structural response (in this earthquake) as a guide to improved design are of limited value. If we knew the exact nature of the shaking to which the structures were subjected, the design requirements could be more precisely established."

Similar views are expressed in the report of the Panel on Strong Motion Seismology of the National Academy of Sciences Committee on Seismology (Steinbrugge and others, 1973).

"Increasing numbers of lives are endangered and substantial economic resources are jeopardized by the growing urban expansion in earthquake-prone areas. This expansion will probably continue for many years. An important factor that complicates any earthquake-hazard-reduction program is that seismologists, geologists and engineers still know far too little about quantifying the various kinds and degrees of earthquake hazard.

"We can mitigate undesirable earthquake effects in a number of ways but not all are currently feasible. Techniques are being developed with which land-use planners will be able to zone, as geologically hazardous, active fault areas, potential slide areas and regions of structurally poor ground. The role of the earthquake engineer is then to reduce the hazards to acceptable levels wherever possible. However the vast majority of the population of earthquake-prone regions, as well as most developed property, are located not directly in fault zones and landslide areas, but in areas where strong shaking can cause loss of life and property damage. It follows then, that the key to an efficient hazard reduction program is an adequate understanding of the destructive seismic forces involved - or in other words the characteristics of the strong ground motions of earthquakes...

"Strong motion seismographs...are used to record the ground motions in the near-source regions of earthquakes, which are of primary importance for engineering purposes. Knowledge of the key elements of strong ground motion - displacement velocity, acceleration and duration - is essential to the development of earthquake-resistant engineering design and is an important factor in understanding basic seismological phenomena such as focal mechanisms of earthquakes.

"Probably no part of the world has a denser network of strong motion instruments than the Los Angeles area. Yet even here, the distribution of instruments was inadequate to provide records of the San Fernando earthquake of February 9, 1971 in many of the major damage areas. Clearly, more and better placed instrument stations are needed to enable scientists and engineers to extract the key information from the observed performance of buildings and other structures. In less-well instrumented areas, it may be virtually impossible to interpret structural performance."

Nowhere are the above observations more pertinent than for the people of California, which is located in one of the more seismically active regions of the world and where knowledgeable authorities have estimated that another earthquake in the San Francisco area the size of the 1906 occurrence could cause the loss of perhaps 10,000 lives and 40,000 injuries (Algermissen and others, 1972, table 50, p. 121). Damage costs for such an event have been unofficially estimated at $1.7 billion (U.S. Geological Survey, internal document, May 1975).

In recognition of these facts, during the period 1966-71, a number of California cities adopted ordinances, generally based on the Uniform Building Code, requiring that motion-recording instruments, such as accelerographs, be installed in buildings with more than six stories. However, in many cases no effective provisions were made for the continued maintenance of these instruments. They tended to concentrate instruments in localized areas of high-rise development, while neglecting other areas; and still no ordinance requires that instruments be placed in low buildings or on the ground. Yet many earthquake fatalities have occurred in buildings of less than 6 stories (all the deaths in the San Fernando earthquake of 1971 for example). Furthermore, the adoption of limited instrumentation ordinances in a few cities of the state is not likely to provide the volume of data required to enable the engineering profession to make satisfactory progress in developing increased earthquake resistance in structures for the protection of life and reduction of property losses. This is particularly true in view of the very large number of factors such as earthquake magnitude, distance from source of energy release, local site conditions, source mechanism, travel path geology, height and width of building, type of building, type of construction material, etc., all of which affect the characteristics of recorded earthquake motions.

In view of this, it became clear that a state-wide program would be required to assure the coordination of planning and effort required to develop a scientifically sound distribution of instruments so as to optimize the knowledge and associated benefits of safety and economy that might be gained from a carefully planned instrumentation system.

Establishment of the Program

Accordingly, the 1971 Legislature enacted, and the Governor signed into law, Chapter 8 of Division 2 of the Public Resources Code (SB 1374, see Appendix A), to establish and monitor a state-wide Strong Motion Instrumentation Program for recording earthquake motions in representative geologic environments and representative structures throughout the state. The program is funded by an assessment collected by local government of 0.007 percent (7 cents per 1,000 dollars) of the estimated building costs as determined at the time of the issuance of building permits. A subsequent amendment sets the lowest assessment at 50 cents in all cases. A history of revenues to date is summarized on Table 1. Cities which had already adopted ordi-

Table 1. History of revenues to the Strong-Motion Instrumentation Fund pursuant to Chapter 8, Division 2, Public Resources Code.

FISCAL YEAR 1971-72		
Third quarter	$ 31,943.98	
Fourth quarter	129,161.27	$ 161,105.25
FISCAL YEAR 1972-73		
First quarter	$114,460.53	
Second quarter	115,074.72	
Third quarter	119,275.02	
Fourth quarter	111,507.17	460,317.44
FISCAL YEAR 1973-74		
First quarter	$121,449.09	
Second quarter	107,963.66	
Third quarter	91,099.05	
Fourth quarter	144,159.50	464,671.30
FISCAL YEAR 1974-75		
First quarter	$ 94,021.00	
Second quarter	96,121.38	
Third quarter	80,532.90	
Fourth quarter	138,585.16	409,260.44
FISCAL YEAR 1975-76 (est.)		
First quarter	$107,578.00	107,578.00 (est.)
Total revenue to date		$1,602,932.43

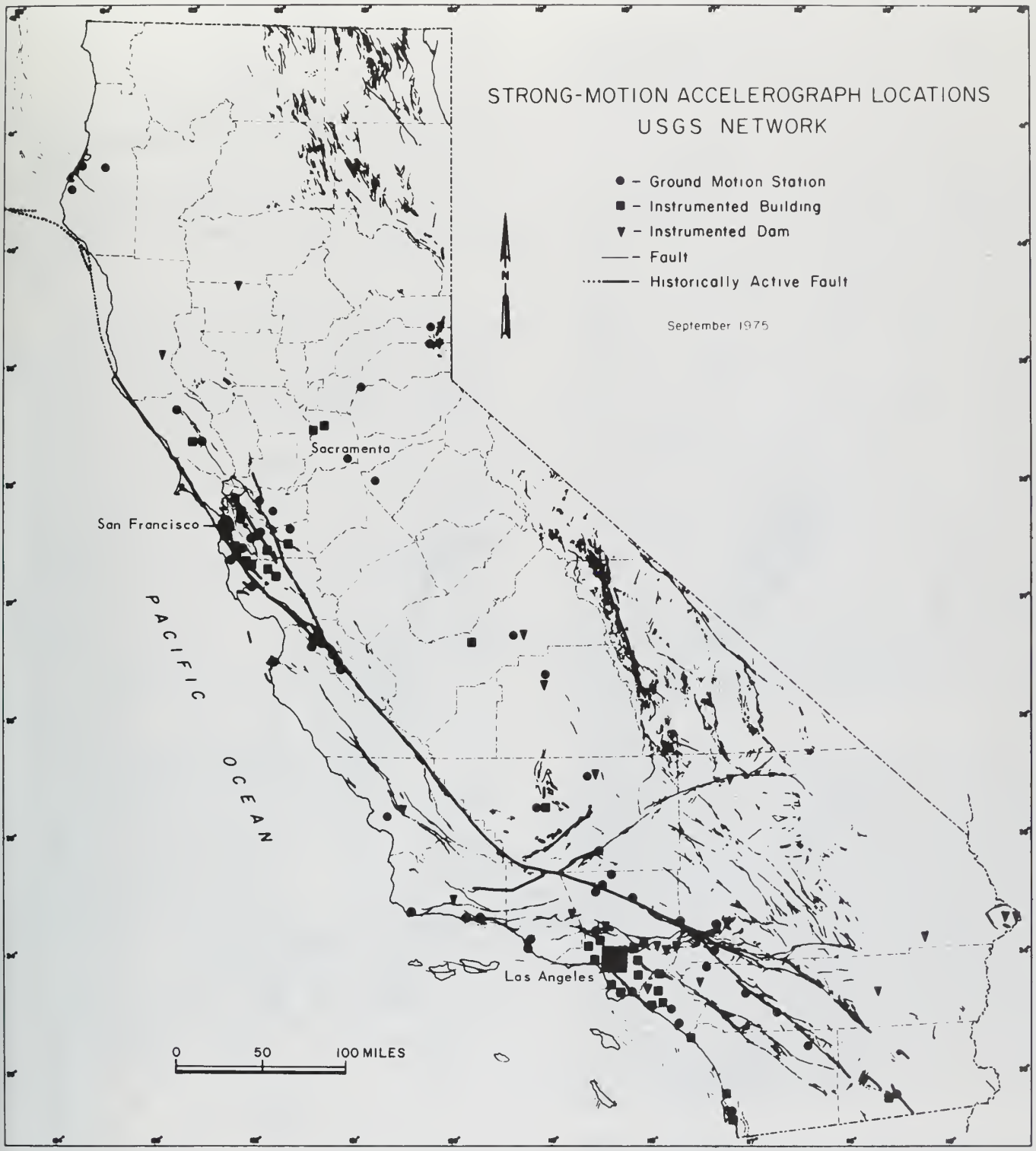


Figure 2. Strong-motion accelerograph locations, USGS network.

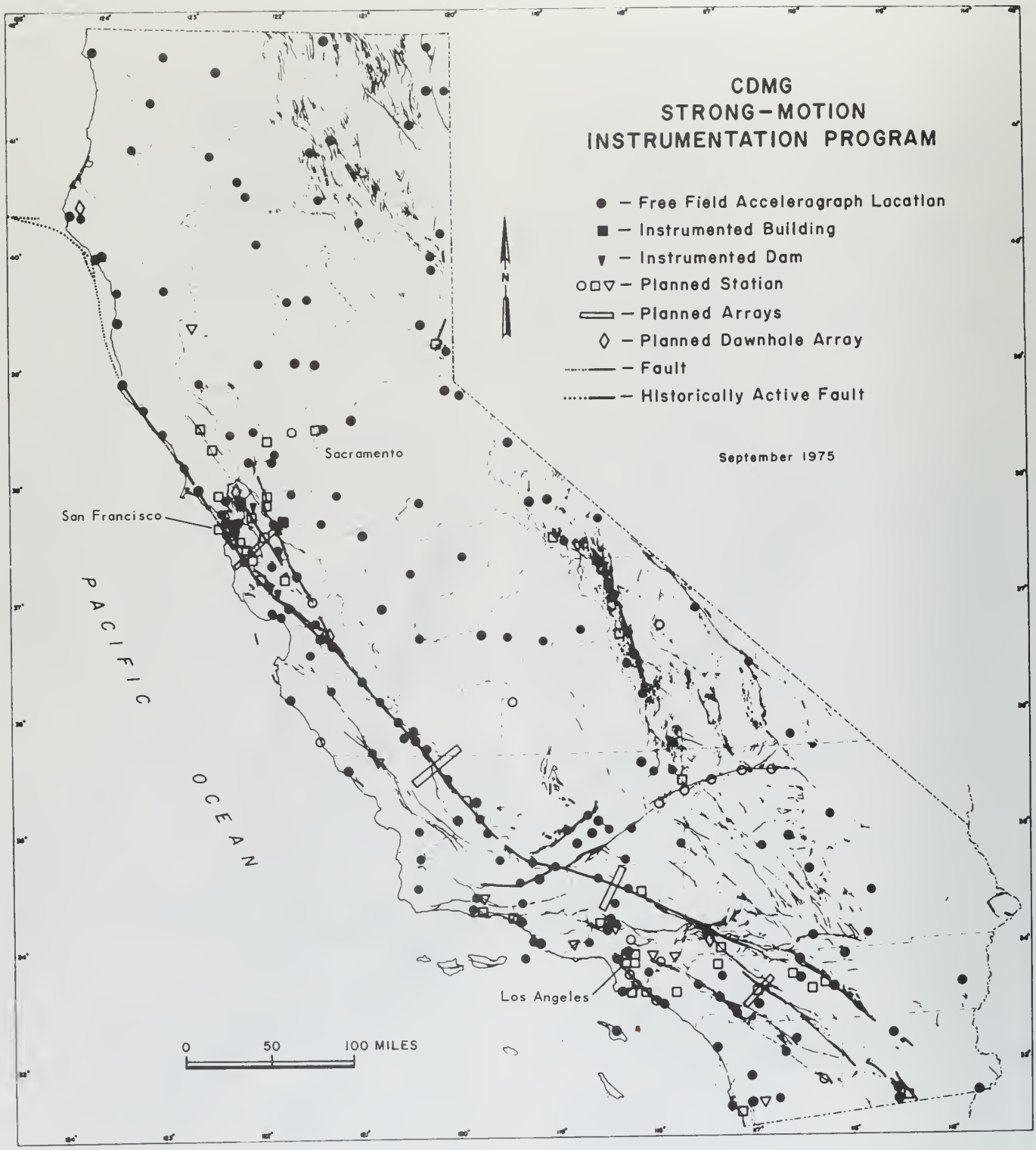


Figure 3. CDMG Strong-Motion Instrumentation Program.

2. Locate instruments in representative structures of all types, such as buildings, dams, bridges, and utilities, to determine the nature of their individual responses to earthquake shaking.
3. Locate sets of instruments in horizontal and vertical arrays so as to record the change in character of motions with increasing distance from the faults on which earthquakes originate.
4. Locate instruments so as to obtain data to compare differences in the motion characteristics of different rock or soil units.

The first, third, and fourth work plans listed above constitute the "Free Field" Instrumentation Program, since they are intended to record the characteristics of ground motions essentially independent of any structures which may be located in the area. The second plan, the instrumentation of structures, will ultimately be the largest in terms of instrumentation requirements. It is intended to provide an improved basis for earthquake-resistant design of structures and facilities of all types.

The planned flow of functions and operations associated with the network planning and the collection and utilization of the data from the California Strong Motion Instrumentation Program (CSMIP) is illustrated in Figure 4. As designated in the enabling legislation, the California Division of Mines and Geology (CDMG) is the agency responsible for the planning, instrument acquisition, installation, and maintenance, record collection, and preliminary interpretation of the data collected. At the present time, the U.S. Geological Survey (USGS), which operates a similar and closely coordinated program funded by the National Science Foundation and other agencies, is providing California a service of data digitization and routine processing

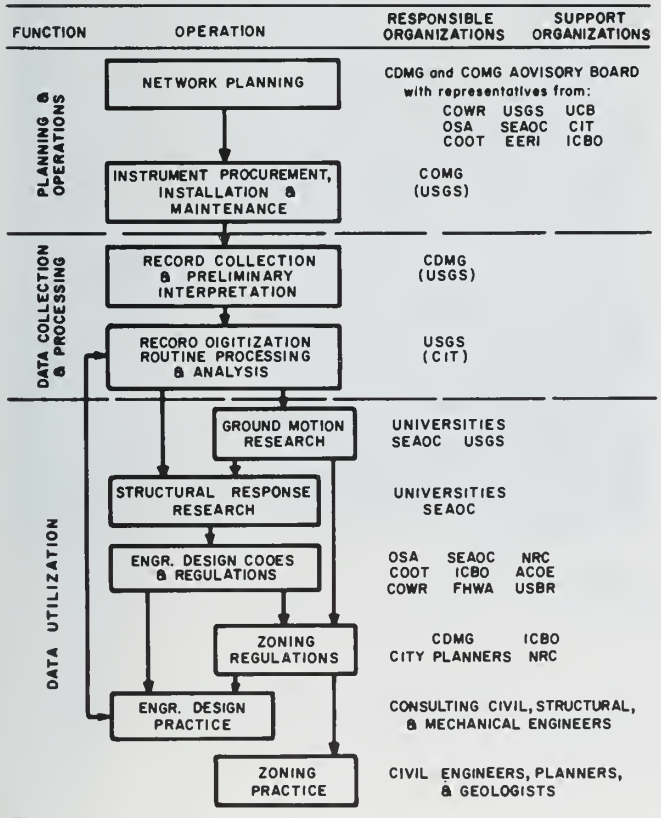


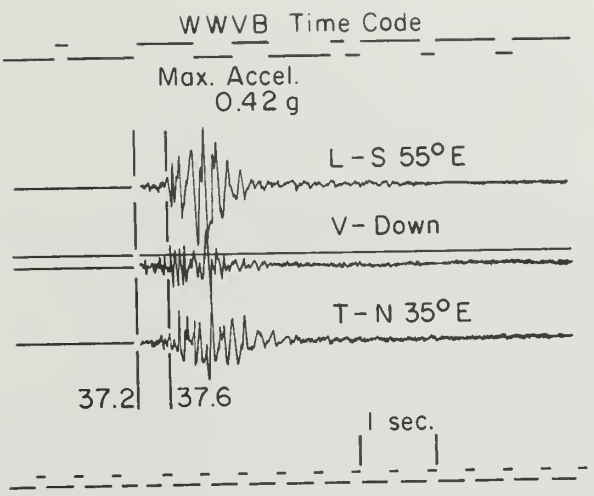
Figure 4. Flow of data from CSMIP.

and analysis utilizing techniques that were developed at the California Institute of Technology (CIT). As long as the number of records collected in any one year is small (10 to 20), this is a satisfactory method of operation. When the CSMIP network grows, and when the number of records collected from any one earthquake turns out to be large, (i.e., the major earthquake that is generally feared), the USGS will have to seek additional funding and possibly additional manpower to process the data in a reasonable amount of time.

After the completion of the routine data processing and analysis, normally, the data are utilized in research studies so that a complete interpretation can be provided. Such studies are conducted primarily in universities such as the University of California (UCB and UCLA), CIT and others across the nation. These research studies are then translated into modifications of engineering design codes and regulations by such organizations as the Structural Engineers Association of California (SEAOC), the International Conference of Building Officials (ICBO), several state agencies such as Office of the State Architect (OSA), California Department of Water Resources (CDWR), or California Department of Transportation (CDOT), and federal agencies such Army Corps of Engineers (ACOE), U.S. Bureau of Reclamation (USBR), Federal Highway Administration (FHWA), and National Research Council (NRC). The research studies are interpreted in terms of recommendations for changes in zoning regulations by such organizations as the California Division of Mines and Geology (CDMG) in connection with their review of seismic safety elements, by county and city planners in the development of seismic safety elements, and ICBO and others. In some engineering design practice associated with special or important structures and facilities, the digitized data may be utilized directly in the design process.

At the inception of the Strong Motion Instrumentation Program, the SMIP Advisory Board recommended the use of accelerographs as the motion recording instruments. (Figure 5 shows two typical installations and an example of an accelerograph record.) This instrument is a device that records the motion of whatever it is attached to—the earth, rock outcrops, building—in terms of acceleration in three dimensions, two horizontal and one vertical. Once installed, the accelerograph remains in a passive standby state until triggered by earthquake motion with an acceleration greater than 0.01 gravity. The accelerations of motion in all 3 instrument directions are then recorded on photographic film for a period of 60 seconds or less, depending on the instrument. The instrument then automatically returns to the stand-by state until re-triggered.

The accelerographs utilized in the CSMIP program are of two types. One is an entirely self-contained unit which records from three sensors oriented to provide data for the three basic dimensions. This unit, which operates on mechanical-optical principles, is about the size of a small portable sewing machine case, and is



Typical accelerogram (accelerograph record)

Typical accelerograph

Typical free field installations

Figure 5. Typical accelerograph, installations, and record

used both for free field installations and for massive structures, such as dams, which do not readily lend themselves to decentralized system instrumentation. The other type is a distributed system operating on an electronic-optical principle, consisting of a central recorder and accelerometers, or sensors, which may be installed in locations remote from the recorder. Distributed system instruments are used in building and down-hole applications where it is desirable that the sensors be remote from the recorder. This distributed type of instrument can record from as many as 12 sensors distributed through a structure, so is equivalent in recording capability to four unitized instruments.

As the program develops, it may be advisable to use additional types of instruments in the program. If such changes are introduced, they will have little or no overall impact on the program. New types of instrumentation will be continuously reviewed and evaluated for applicability to, or improvement of, the developing network.

ACCOMPLISHMENTS

Free Field Instrumentation Programs

It is clear from the deployment of instrument stations in the pre-1971 networks of other state agencies and the U.S. Geological Survey, seen in Figures 1 and 2, which show instruments concentrated in certain limited regions, that a more uniformly spaced network was needed. Accordingly, when the California Strong Motion Instrumentation Program was initiated, highest priority was given to creating a statewide free field network based on the following guidelines:

1. At least one significant record should be obtained for any potentially damaging earthquake (greater than magnitude 6) occurring anywhere in the 156,000 square miles of the state. This requires the careful placement of instrument stations so as to cover all potentially seismically active areas and, particularly, to provide coverage of many areas having no previous instrumentation.
2. The density of instruments should be greater in the more seismic parts of the state and particularly near fault zones which offer the best chance of producing useful records.
3. Instruments should be located so as to obtain records that compare any differences in motion which develop on differing rock or other soil conditions.
4. Instruments should be located with a higher density in the more densely populated areas, where a more direct damage-reduction benefit will ultimately be achieved.
5. Instruments should be located so as to record the change in character of motion with increasing distance from the earthquake source or causative faults.
6. Some instruments should be located in areas of potentially unstable slopes, to record the characteristics of earthquake-induced motions that initiate such problems as sliding, slumping, and subsidence.

Figure 3 shows the network of about 180 instruments installed in the CSMIP program from its inception through August 1975. An additional 40 sites have been selected on the advice of the Earthquake Engineering Research Institute (EERI), and installations are nearing completion.

All too often in past earthquakes in California and elsewhere, no analyzable record has been obtained close enough to areas in which damage has occurred, so the interpretation of the earthquake effects has been unsatisfactory. To overcome this problem, records from past earthquakes were reviewed and guidelines developed to space accelerographs about 30 miles apart along any fault capable of producing an earthquake of magnitude 6 or greater. After considering the locations of all instruments installed by others, the CSMIP fault-watch accelerographs are deployed. This segment of the CSMIP program is essentially completed and integrated with the SMIP general free-field phase. The total system to date consists of 220 instruments already installed or designated for installation. Minor additions to this initial network will be required, however, bringing the total instruments required to about 280. (See Appendix D for detailed discussion.)

In order to accomplish the other aspects of the free field program, plans are under way to set out special arrays of instruments to determine the attenuation of motions with distance from source, the effects of source mechanism, and the influence of local soil conditions on ground motion characteristics. It is recognized that the specified characteristics and reductions of motion might be different for thrust faults, normal faults, or strike-slip faults; but that a basic pattern of instrumentation arranged outward in different directions could be similar for each type of fault. The spectral characteristics and attenuation of motion are expected to be influenced by geologic structures along the transmission path (Trifunac and Udwadia, 1974). For example, propagation of motion is expected to be different on opposite sides of the fault if there is a distinct contrast in the geologic structure on opposite sides of the fault; or the motion may be significantly altered by the presence of a distinct change in the geologic structure in the path of the propagating waves. Finally, the factor that many believe to be the most significant is the influence of the local geologic and soil conditions, particularly soil layering with distinct dynamic characteristics. In this case, the use of "down hole" instrumentation is required if a satisfactory interpretation of the results is to be accomplished. Furthermore, it has been suggested that each down hole array should be comprised of at least three separate holes arranged in a triangular pattern with each leg of the triangle being perhaps a hundred metres on a side.

The implication from this brief outline is that it is desirable to have perhaps 20 instruments to record ground motions on the surface and several sets of down hole instruments to record subsurface motions for any potentially damaging earthquake and two to three times that number recording major events. These instruments would be arranged radially from the source in different directions and on representative geologic structures and soil deposits. A number of potential source areas are to be instrumented to ensure a high probability for obtaining the needed data within a reasonable time. This instrumentation plan would require at least 200 instruments.

At this time, the arrangement of instrumentation that can be considered most valuable for studies of earthquake effects on unstable soil, such as liquefaction and landsliding, is sets of two or more instruments, some of which are placed on potentially unstable sites and others on "firm" soil nearby. Arrays of instruments for this purpose should be subarrays of the more extensive arrays designed to study the effects of source, transmission path, and site conditions on the spectral characteristics of the base ground motion. (See Appendix D for typical examples of regional arrays.) these sub-arrays are expected to require 40 instruments in addition to those in the basic ground motion arrays.

Summarizing the above, the minimum number of instruments required to complete the "free-field" ground motion record objectives of the CSMIP program will be approximately as follows:

Free-field distribution throughout the state	280
Horizontal and vertical arrays to study change of character with distance and motion variations in soil	200
Arrays in potentially unstable soils	40

Building Instrumentation Program

Studies of the response of representative types of buildings at damaging levels of response are of second highest priority. Even without knowing the ground motion at the site, measurement of structural response can lead to improvements in structural design, particularly if the response is at levels corresponding to the threshold of damage. Of the 60 instrumented buildings from which records were obtained during the San Fernando earthquake of February 9, 1971, only two sustained structural damage. Additional records of such damaging motion are necessary to advance understanding of the design requirements necessary to minimize damage to prevent collapse of buildings. In addition, records must be obtained from "low-rise" buildings, which are more sensitive to potentially damaging motions.

The building types to be instrumented should be representative (with respect to size, type of framing, construction materials, date of design and construction, and foundation conditions) though relatively simple in framing and design so that the response can be readily interpreted. In this way, the knowledge acquired can be most readily transferred to improvement in design practice. The input motion to the structure must be measured and, if the interaction of the structure with the foundations soils is apt to be significant, additional instrumentation will be required to determine these interacting motions. The areas in which the buildings to be instrumented are located generally should be those with the higher probability for potentially damaging earthquakes. On the other hand, significant buildings located in areas of infrequent but large earthquakes cannot be overlooked. These areas provide the greatest potential for a total collapse of buildings or a complete failure of a dam or other structure. More instrumentation might be installed in each structure in the more active areas than is used in the less active areas, but in all cases, sufficient instrumentation must be used so that the input motion and the basic response can be properly identified.

Building response is reasonably well defined by accelerometers because the structure reacts selectively to the input motion according to its individual response characteristics, and the acceleration values may be easily converted to velocity or displacement values, if desired. The objective of structural-response instrumentation is to determine the deforming motions of the structures for the level of input motion occurring during the earthquake. Since all structures exhibit nonlinear behavior, there will be variations of the structure's deforming motions with variations of the level of input motion. Furthermore, since some structural damage is to be expected in major earthquakes, a significant change in the nature of the structure response is to be expected as these structures experience damaging motion.

At present, the instrumentation most widely used in buildings, aside from the CSMIP program, is that required by building code ("...three approved recording accelerographs... The instruments shall be located in the basement, midportion, and near the top of the building."). Such instrumentation is inadequate for definition of the complete deformational response of the building. For example, with the instrumentation presently employed, it is impossible to clearly distinguish between lateral and rotational response of the building. This can be an important factor even in "symmetric" buildings as has been shown in forced vibration tests as well as in analysis of records of the San Fernando earthquake. With this presently employed instrumentation, it is also impossible to determine the contribution of the vertical motion to the building response. This also can be an important factor, as has been shown in analytical studies of shear-wall structures. It can also be shown that, with only two instruments at the "midportion and near the top of the buildings", it is impossible to obtain any definition of the various responses of a given building during an earthquake.

Furthermore, to date, little consideration has been given to the measurement capacity of the code mandated accelerometers that are used in structural response studies. For example, it can be shown that, even with ground motions equal to 1.0 g, buildings over 30 stories high will not experience peak accelerations greater than 0.5 g. On the other hand, for short buildings close to faults, the maximum accelerations may exceed 1.0 g at the roof. Thus, the instrumentation should be appropriate to the structure being instrumented and to its location relative to faults, as well as to the interpretation to be made. These inadequacies have been considered and are eliminated in the CSMIP.

For most structural applications, the standard type of accelerographs used in CSMIP are compact recording packages with remote accelerometers. Such units are on the market today at approximately twice the cost of comparable instrumentation with standard accelerographs. Furthermore, they rely on electronics to a greater extent than the standard accelerographs. The increased reliance on electronics will undoubtedly increase the maintenance to some extent, but the increased information and flexibility in placement of the sensors offsets these disadvantages.

In order to ensure an appropriate selection of buildings for instrumentation, the Advisory Committee has sought the advice of special committees of the Structural Engineers Association of California (SEAOC). (See Appendix E.) These committees have provided a set of guidelines indicating relative percentages of buildings to be instrumented, classified as to type of framing, height, and location relative to faults. These recommended guidelines indicate that it would be desirable to instrument about 500 buildings, located throughout the state, in which damage is likely to occur in future earthquakes. However, the Advisory Board, upon careful consideration, has determined that instrumentation of 400 buildings would fulfill the requirements of a balanced program. Allowing an average of about eight recording channels per building, the 400 systems, consisting of 3200 recording channels will be equivalent to the recording capability of 1100 standard accelerographs.

To date, the SEAOC committees have made specific recommendations for instrumentation of 53 buildings with systems involving a total of 431 recording channels (see Appendix F); but additional recommendations will be made over the next several years as funds become available for instrument purchase and installation.

Instrumentation for Structures Other Than Buildings

In addition to buildings, it is also desirable to determine the seismic response of a variety of other structures critical to the public welfare such as dams, bridges, and tanks. Considerations for selection of such structures for instrumentation are similar to those for buildings. The instrumentation of two or three dams, three or four bridges, several storage tanks and covered reservoirs, and some miscellaneous types of structures in a number of different areas, each with an average of four or five instruments, indicates a need for about 500 accelerographs.

The Advisory Board has requested the advice of the California Department of Water Resources and the California Department of Transportation in selecting sites for instrumented dams and transportation facilities, respectively.

Instrumentation for Water and Power Supply Systems

Experience in previous earthquakes has shown that one of the most critical needs of the damaged areas is the continued functioning of water and power supply systems. Accordingly, it has been considered by the Advisory Board that its mandate to recommend instrumentation for representative structures includes the facilities and systems required for water and power supply. In fact, since very little attention has been paid to the seismic response of these systems in the past, this might well be one of the more important areas where measurements of seismic response can contribute most to improved design and performance.

Since entire systems are involved, multiple instrument arrays will be needed in different regions of the state. The Advisory Board has therefore invited the California Water and Power Earthquake Engineering Forum to accept responsibility for recommending instrument locations for water and electrical power systems. The Forum appointed a committee consisting of representatives of the following agencies: Metropolitan Water District of Southern California, Los Angeles County Flood Control District, Los Angeles Department of Water and Power, San Diego Gas and Electric Company, East Bay Municipal Utility District, City of San Francisco Water Department, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, California Department of Water Resources, Southern California Edison Company, and Pacific Gas and Electric Company. Formal recommendations of the Forum are presented as Appendix G, which indicates that the desirable number of accelerographs will be 244.

In addition, the advice of the Public Utilities Commission is being sought concerning the need for instrumentation of sewage systems, gas and liquid fuel systems, and communications facilities. Instruments needed to determine the seismic response of these systems to ensure their continued functioning following a major earthquake is believed to be about 200.

REQUIRED INSTRUMENTATION

From the information presented in the preceding pages, it is indicated that the number of instruments required for an adequate program of instrumentation to be provided by the Strong Motion Instrumentation Program will be approximately as follows:

Free field ground motions	520 accelerographs
Building systems	400 accelerographs
Structures other than buildings (dams, bridges, tanks)	500 accelerographs
Water and power supply systems and other utilities	444 accelerographs
	1,864

Clearly, other types of instruments may be required also, but they will be substituted as the need arises.

	Accomplished to Nov. 15, 1975	Required to complete program
Free field sites selected	279	241
Free field instruments purchased	290	230
Free field instruments installed	195	325
Buildings selected for instrumentation	52	348
Building instrument systems purchased	30	370
Buildings instrumented	3	397
Instruments purcahsed for installation on structures other than buildings	70	430±
Structures other than buildings selected for instrumentation	12	113±
Structures other than buildings instrumented	3	122±
Instruments installed on structures other than buildings	14	486±
Instrument stations selected for water and power supply systems	244	200

PROGRAM FUTURE

Projection of the program to the conclusion of its development and attainment of a stable, operational phase depends upon several basic assumptions. Chief among these is that of a continuing level of revenue equal to that currently in being. Others include such factors as no significant technological breakthrough in instrumentation, which could have the effect of increasing or decreasing the program size, and no significant change in relative instrument cost.

Further, the projections into duration of the developmental phase of the program are controlled by the relatively fixed costs of personnel support and mandatory costs for instrument maintenance. The personnel costs will be reducible only in the latest stages of the development phase, as support needs decrease. The maintenance costs will continue to increase as the number of installed instruments increases to the completion of the installation phase. At this time, these costs will stabilize as the program continues in the purely operational phase. The remaining, controllable costs, which will be adjusted as needs dictate, are those for the procurement and installation of instrumentation.

In consideration of the foregoing and using cost factors derived on Table 2, it is estimated that the procurement and installation phase, involving 1,864 instruments, will be completed in the year 2035. Figure 6 is a graph curve depicting the rate of instrument installation and demonstrating the projected growth-completion date. Figure 7 is a chart providing further detail on costs and cost distribution throughout the program development. Another requirement of the program not considered in the preceding pages is an additional requirement for funds required in the event of a major earthquake. In this case, considerable expenditures will be needed to process the records produced and to interpret them in terms of the local soil conditions and characteristics of structures at stations where particularly important records are obtained. During the development of the program, the controllable funds allocated to instrument procurement will be available for redirection, should the need arise. After the program enters the purely operational phase, the revenues will exceed the operational-maintenance costs by approximately $40,000 per year, as is apparent from Figure 7. This average in revenue will be adequate to provide for the building of an "earthquake contingency reserve" of perhaps $100,000 and should allow an eventual slight reduction in the fees upon which the revenue is based. After attainment of an adequate reserve level, consideration may be given to a reduction of the fees levied for program support.

Table 2. Derivations of estimated costs.

PURCHASING AND INSTALLING INSTRUMENTS		
Free field (1,461)	$3,652,500	
Structure system (400)	320,000	
Down-hole system (3)	45,000	$4,017,500
MAINTAINING 1 INSTRUMENT FOR 1 YEAR		
Electronics Technician salary	$17,540	
Optimum workload	÷150 instruments = $117	
Travel expenses each Technician	$8,500	
	÷150 instruments = 57	
Parts replaced	40	$214
SUPPORT PERSONNEL FOR 1 YEAR		
Associate Geophysicist	$25,315	
Assistant Geologist (2 @ $20,808 ea)	41,616	
Civil Engineering Technician	19,828	
Electrician	18,432	
Stenographer	11,390	$116,581

CONCLUSION

The instrumentation program envisaged in the preceding pages will go far toward continuously providing the data required by the structural engineering profession to solve many of the major problems in engineering seismology and earthquake engineering. The importance of completing such a program cannot be overemphasized if earthquake-resistant design is to advance to the point where it can provide the required degree of public safety with a maximum of economy in the costs of engineered construction. A total cost of nearly $12 million expended over a 60-year period will be required for the ultimate completion of the Strong Motion Instrumentation Program network. This is a reasonable price to pay for a system of 1,864 instruments that will provide data to structural engineers to apply to future building design and that will result in the saving of countless lives and untold damage costs. Recent earthquakes, such as that in San Fernando in 1971, have resulted in severe and potentially life-endangering damage to modern buildings constructed to modern standards. These experiences dramatically point out the need by the structural engineering profession for the information to be provided by the Strong Motion Instrumentation Program for application to structure design technology for improvement of the earthquake resistance performance.

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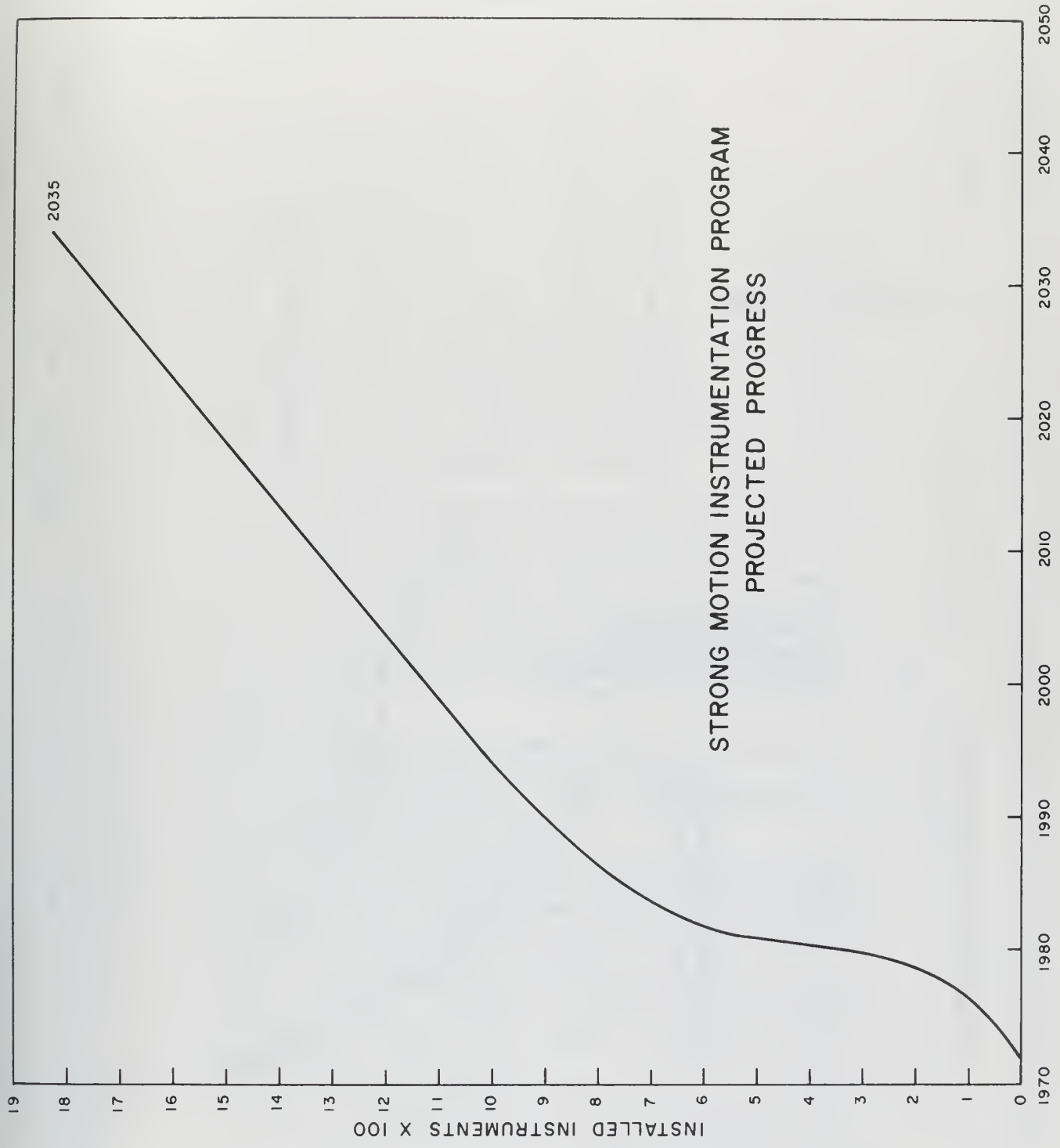

Figure 6. Strong-Motion Instrumentation Program progress.

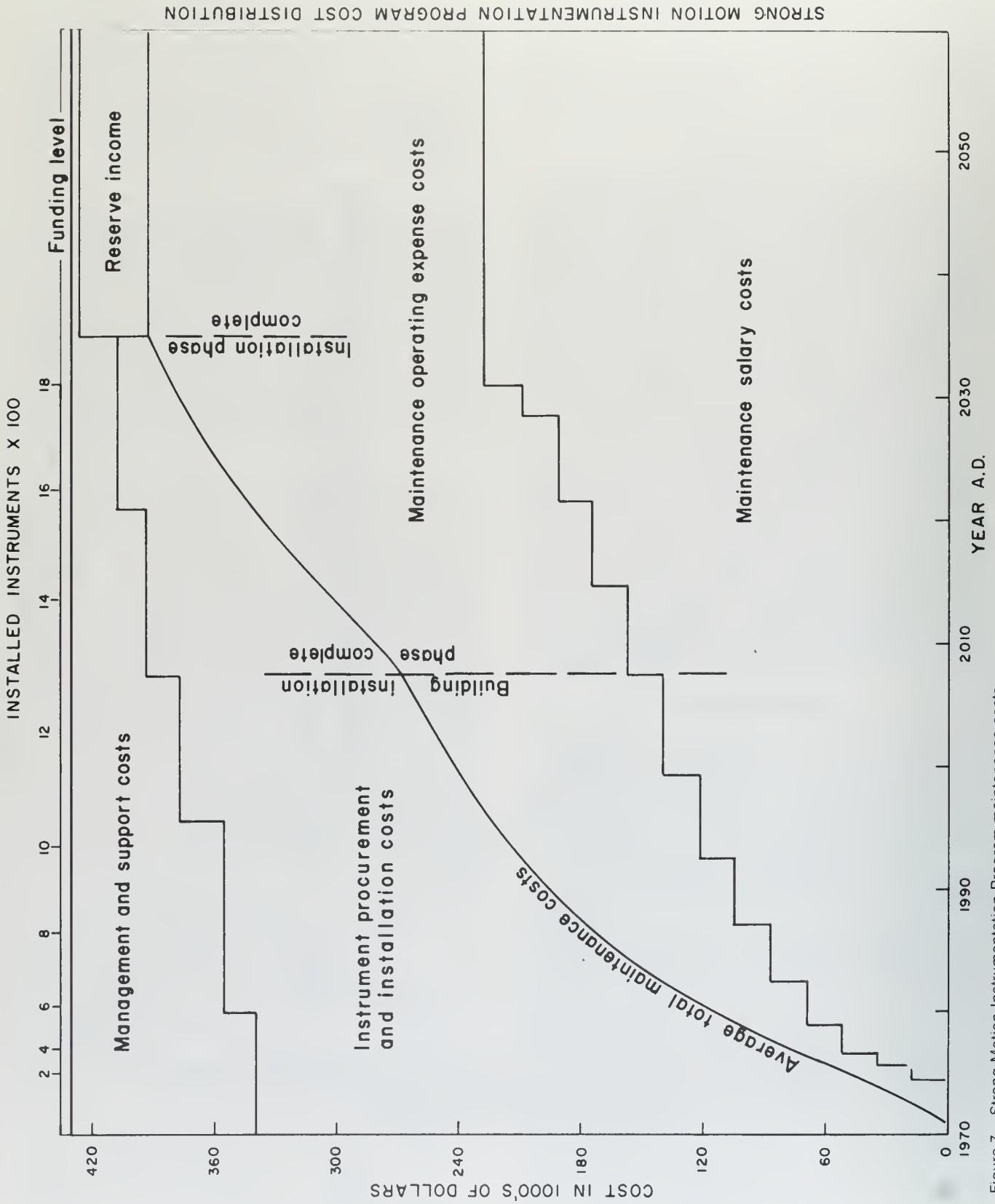
STRONG MOTION INSTRUMENTATION PROGRAM COST DISTRIBUTION
INSTALLED INSTRUMENTS X 100
Funding level
Reserve income
Installation phase complete
Maintenance operating expense costs
Maintenance salary costs
Building installation phase complete
Management and support costs
Instrument procurement and installation costs
Average total maintenance costs
COST IN 1000'S OF DOLLARS
YEAR A.D.
2 4 6 8 10 12 14 16 18
420 360 300 240 180 120 60 0
1970 1990 2010 2030 2050

Figure 7. Strong-Motion Instrumentation Program maintenance costs.

APPENDIX A

Senate Bill No. 1374

CHAPTER 1152

An act to add Chapter 8 (commencing with Section 2700) to Division 2 of the Public Resources Code, relating to earthquake safety, and making an appropriation therefor.

[Approved by Governor October 19, 1971. Filed with Secretary of State October 19, 1971.]

The people of the State of California do enact as follows:

Chapter 8. Strong Motion Instrumentation Program

2700. There is hereby established in the State of California a strong-motion instrumentation program for the purpose of administering the program and of acquiring strong-motion instruments and installing and maintaining such instruments as needed in representative geologic environments and structures throughout the state.

2701. The division shall organize and monitor the program with the advice of an advisory board appointed by the State Geologist which shall include, but not be limited to, a representative of the Earthquake Engineering Research Institute, the National Oceanic and Atmospheric Administration, the United States Geological Survey, the Structural Engineers Association of California, the Earthquake Engineering Research Center at the University of California, Berkeley, and the Earthquake Engineering Research Laboratory at the California Institute of Technology.

2702. The division shall purchase and install instruments in representative structures and geologic environments throughout the state as deemed necessary and desirable by the advisory board.

2703. The division shall negotiate with the National Oceanic and Atmospheric Administration or other competent agency an agreement by which the administration or such agency shall maintain and service the strong-motion instruments installed, and shall negotiate with appropriate state agencies to collect and interpret all records from the instruments and to make the records available and interpretations to all interested parties.

2704. It is the intent of the Legislature in enacting this chapter to provide adequate instrumentation throughout California.

2705. All counties and cities shall collect a fee from all applicants for construction permits which shall be equal to .007 percent of the estimated construction cost of the structure.

2706. All fees collected pursuant to Section 2705 shall be deposited in the State Treasury in the Strong-Motion Instrumentation Special Fund, which fund is hereby created, to be used exclusively for the purposes of this chapter. All moneys in such fund are continuously appropriated to the division for the purposes of this chapter.

2707. The division, upon the advice of the advisory board, whenever it determines that an adequate instrumentation program has been achieved, may reduce the fee levied against building permits as provided in Section 2705 to a level sufficient to maintain the program established pursuant to this chapter.

2708. Any city or county that has adopted an ordinance requiring the installation of accelerographs in structures shall be exempted from the provisions of Section 2705 if both of the following has occurred:

(a) A minimum of one structure has been instrumented with three accelerographs installed in accordance with such ordinance prior to October 1, 1971.

(b) The State Geologist has received, on or before June 30, 1972, a written request of the governing body of such city or county that they be exempted.

APPENDIX B
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APPENDIX C

OTHER STRONG MOTION SYSTEM OPERATORS

Following is a list of agencies, other than the California Division of Mines and Geology, the California Department of Water Resources, and the United States Geological Survey, that operate strong motion instrumentation systems within California:

California Department of Transportation
U. S. Army Corps of Engineers
U. S. Bureau of Reclamation
U. S. Veterans Administration
Metropolitan Water District of Southern California
Southern California Edison Company
Pacific Gas and Electric Company
California Institute of Technology
University of California, Berkeley
Building owners (as required by local ordinance)

The total number of instruments operated by these organizations and not included in the California Strong Motion Instrumentation Program/U. S. Geological Survey integrated net is approximately 120.

APPENDIX D

DEVELOPMENT OF AN OPTIMUM STRONG MOTION INSTRUMENT NETWORK FOR CALIFORNIA

by
Dr. R. B. Matthiesen
U. S. Geological Survey

The following discussion focuses on model instrumentation arrays that would provide the "ideal" set of strong motion records from earthquakes in different regions of California. As examples, model networks of instrumentation for two regions of California are outlined without regard to which agencies might install and maintain parts of the total network that is defined. Similar outlines are being prepared for the other regions of the state. When those outlines are complete, the order of priorities, the probable participation of other agencies, and the resulting model network that should be supported by the California Strong Motion Program will be defined. Finally, the relative cost of installation and maintenance must be defined so that the cost of maintaining different levels of this model network can be determined.

In order to define the model networks and arrays that should be installed in the state, it is convenient to treat the major seismic regions of the state as separate units. For this purpose, the state has been subdivided into the following regions: (1) the Cape Mendocino region, extending along the coast from Fort Bragg to the Oregon border; (2) the north coast region extending from Fort Bragg to San Jose; (3) the central coastal region extending from San Jose to the Carrizo Plain; (4) the south-central region, extending from the Carrizo Plain to Palm Springs; (5) the Imperial Valley-San Jacinto region, extending from Palm Springs to the Mexican border at Calexico; and (6) the Sierra region, extending from Mojave and Bakersfield to Honey Lake. The Santa Barbara coast, the Los Angeles Basin, and the south coast near San Diego are considered to be sub-regions to these major regions. The remainder of the state is considered to require only a minimum level of instrumentation to obtain at least one record from any potentially damaging earthquake of magnitude 6 or greater. This regionalization is obviously dominated by the San Andreas fault system and the Owens Valley fault system, the three sub-regions being associated with secondary fault systems. For the present, only the model networks of strong motion instrumentation for the first two regions are discussed.

Cape Mendocino Region

This is a region of frequently occurring small earthquakes and some large earthquakes but no indication that a major earthquake is highly likely. As indicated in Figure D-1, significant levels of ground motion are to be expected at the Ferndale and Eureka sites at 10 to 20 year intervals. This is the most active region of the state in terms of numbers of records of ground motion with peak accelerations greater than 0.01g. In view of this activity, the region should be intensely instrumented for studies of ground motion, particularly for the study of the influence of local soil conditions on the amplitude of the motion. The region is less suitable for the study of source mechanisms or the effects of the radiation patterns and transmission path because many of the earthquakes are located off-shore. Low-rise buildings and bridges in the region might be suitable for instrumentation as well.

An outline for a model network of instrumentation in the Cape Mendocino region is indicated in Figure D-2. The existing instrumentation at ground stations provides a

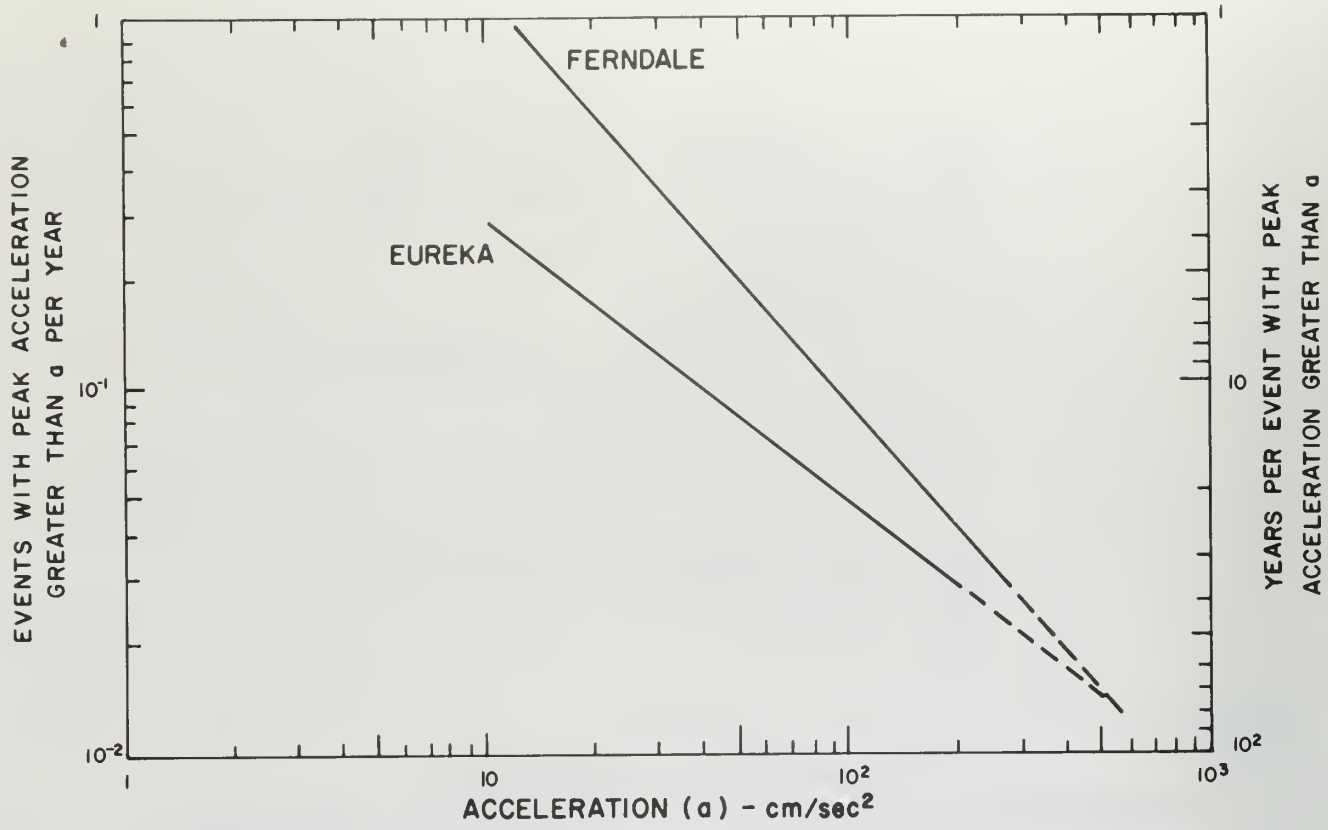


Figure D-1. Recurrence curves for stations in northern California

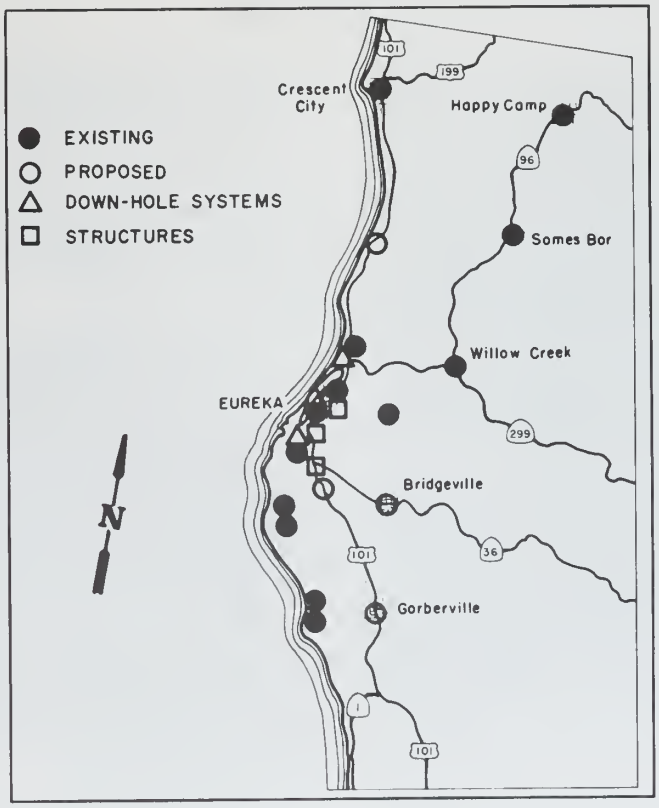


Figure D-2. Strong-motion instrumentation for the Cape Mendocino region.

reasonable coverage in terms of obtaining at least one record from any magnitude 6+ event that might occur on-shore or close enough off-shore to be potentially damaging, although some additional instruments for this purpose are proposed.

The major instrumentation proposed for this region is an intensive array for determining the influence of local soil conditions on the amplitude of ground motion. The array proposed for this purpose consists of a three-hole down-hole array in the alluvial delta of the Eel River and two single hole down-hole systems along the margins of Humboldt Bay. At each hole, at least two sub-surface triaxial transducer packages should be installed along with four surface triaxial units. The total instrumentation will consist of 10 to 12 three component transducers down-hole and 20 three component surface units. These will be deployed in a closely spaced array to study the amplification of motion through the soil layers and the variation of the motion over short distances on the surface.

In addition to the instrumentation to study soil effects, six to ten buildings and three or four bridges in the area should be instrumented. The selection of specific structures will require an on-site inspection. There are no major dams known to be in the area of high activity, although Ruth Dam on the Mad River should be considered for instrumentation. Because of the importance of understanding the response of nuclear power systems, the state should determine if the instrumentation that is installed at the Humboldt Bay Nuclear Power Station is adequate. Additional instrumentation should be installed there if the present amount of instrumentation is found to be minimal.

North Coast Region

The segment of the San Andreas fault in the North Coast Region is one of the three fault segments on which a magnitude 8+ earthquake has occurred in historic times. In the past 40 years, the recurrence of maximum peak accelerations at individual stations in this region has been relatively low, as indicated in Figure D-3. Significant motions are most likely to result from a magnitude 8+ event on the San Andreas fault or a magnitude 7+ event on the Hayward fault. Significant motions also may occur from smaller events on these or other faults, but from the available evidence on recurrence of events on specific faults in this region, it is not believed to be reasonable to attempt detailed studies in conjunction with these other events. In addition to the general network of ground installations, the primary purpose of the instrumentation in this region should be to obtain that minimum amount of data necessary to permit an adequate interpretation of the effect of a repeat of the 1906 earthquake on the San Andreas fault or the 1836 or 1868 events on the Hayward fault. By proper planning, such instrumentation will provide the minimum desired data from many smaller events also.

In 1906, the fault rupture extended for 200 miles along the fault. Since the current geologic estimates for the recurrence of this type event range from 100 to 400 years, it is not now reasonable to provide a dense network of instrumentation to record such an event. The proposed instrument arrays for this region, indicated in Figure D-4, are intended to provide intensive instrumentation along selected alignments extending transverse to the system of faults in this region. There are two segments of the San Andreas fault in this region along which it is possible to locate instruments to the west of the fault: the Tomales Bay-Point Reyes segment and the Crystal Springs segment. It is proposed that the intensive arrays of instrumentation for studies of ground motion be concentrated along two transverse alignments associated with these two segments of the fault.

The Crystal Springs array is being developed as an extension of the APEEL array operated by the USGS. This array should extend from Half Moon Bay on the Pacific coast to the Central Valley. This provides for the study of the attenuation of motion with distance from the San Andreas, Hayward, and Calaveras faults. Since there are many different soil conditions along this alignment, a measure of the effect of these differences will be obtained. Additional data on the effect of the soft bay muds could be obtained by installing down-hole systems at several points. Except for the special down-hole systems being developed at Richmond in conjunction with the University of California, added expense of installing down-hole systems is not thought to be cost effective in view of the long recurrence interval in this region. A dense network of instruments to study the source mechanism and rupture propagation should be installed along each side of the three major faults that are crossed. In addition, concentrations of instrumented structures should be planned along this alignment. San Mateo County has a complex of low-rise buildings of different construction within a mile of the San Andreas fault on this alignment. Low-rise office and apartment buildings in Belmont, San Carlos, and Redwood City are along this alignment near the San Andreas fault; low- and high-rise buildings are along the alignment in Hayward; and one-story industrial buildings are located in the Redwood City, Hayward, and Dublin areas along this alignment. The San Mateo Bridge crosses San Francisco Bay on this same alignment and, as a minimum, several of the piers of the Bridge should be instrumented. A major freeway interchange already exists near low Crystal Springs reservoir, and another is partially completed at the Bayshore freeway in San Mateo. Both of these should be instrumented.

An array crossing the Tomales Bay-Point Reyes segment of the San Andreas fault could be developed to extend from Point Reyes through Santa Rosa to Davis in the Central Valley. This would cross the San Andreas, Healdsburg, and Midland fault zones in regions that have been active in historic times. A dense deployment of instruments near each of these faults is proposed to provide for the study of source effects.

Significant effects of the local soil conditions were reported from Santa Rosa in both 1906 and 1969, so that an array of surface instruments is proposed in that region to study such effects. Several low-rise buildings in Santa Rosa should be instrumented as well. The Monticello Dam on Lake Berryessa has been the subject of dynamic analysis and forced vibration tests, and the Bureau of Reclamation is planning to provide extensive instrumentation of the dam. Since this dam is along this general alignment from Point Reyes to Davis, it is proposed that additional instruments be placed in the vicinity of the dam to completely define the input motion at the dam site.

These two alignments can be considered to terminate at Stockton and Sacramento. The spacing of ground installations need not be dense in Central Valley portion, but long period structures in this area can receive significant excitation from a major earthquake on the San Andreas or Hayward faults. Therefore, it is proposed that several high-rise buildings and other long period structures in these two cities be instrumented. It is also possible that soil-structure interaction may play a significant role in the response of

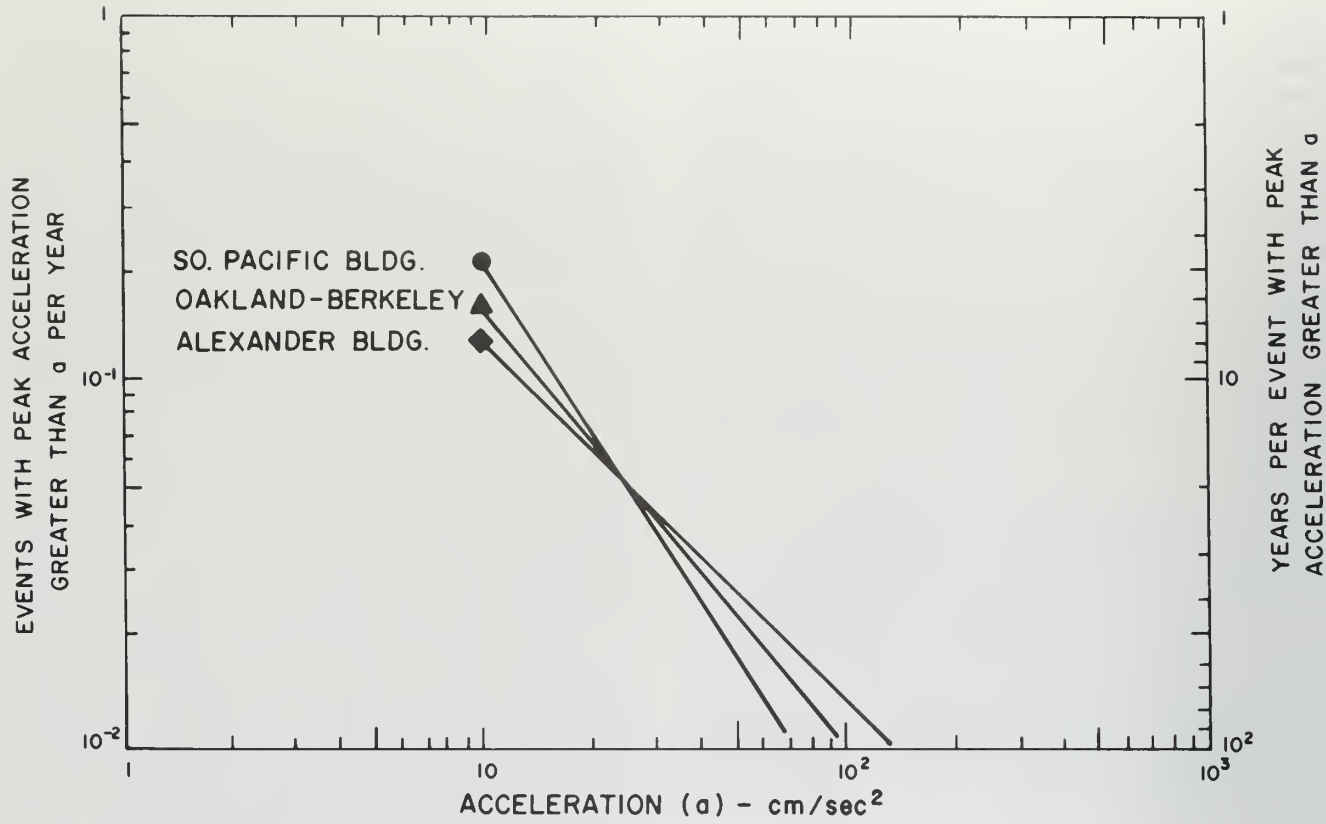


Figure E-3. Recurrence curves for stations in northern California.

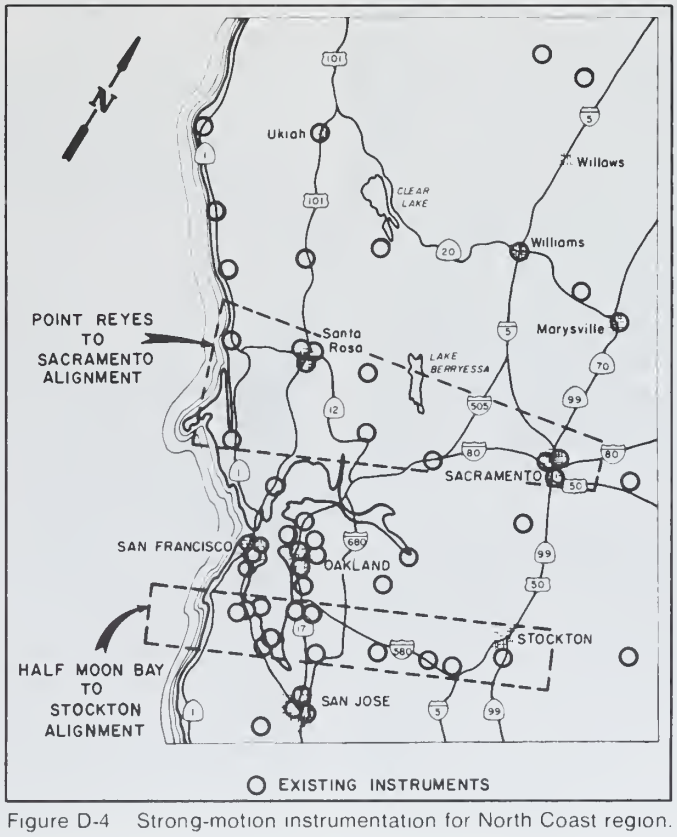


Figure D-4 Strong-motion instrumentation for North Coast region.

some of the stiff structures in this area, and appropriate consideration of this effect will be made in placing of instruments. The Ranch Seco Nuclear Power Plant near Sacramento has a minimum level of instrumentation at present. This should be reviewed for possible improvement if warranted.

Finally, a minimum level of instrumentation in the remaining parts of the San Francisco Bay is proposed. A secondary alignment of instruments transverse to the major faults already exists and extends across San Francisco to Yerba Buena Island and through Oakland. Several of the high-rise buildings in San Francisco are already instrumented, but some additional high-rise buildings should be considered. Similarly, instrumentation is proposed for several of the high-rise buildings in Oakland and San Jose. Several low-rise buildings in San Francisco, Oakland and San Jose should be instrumented as well. Additional ground installations near clusters of buildings are also proposed to aid in the study of the influence of soil-structure interaction on ground motion and on structural response. A minimum level of instrumentation of the San Francisco-Oakland Bay Bridge and the Golden Gate Bridge should be considered. Except for the additional instrumentation of freeway bridges indicated above, the three freeway bridges that the California Department of Transportation has already instrumented in this region is considered to be an appropriate level of instrumentation for this type of structure in view of the low recurrence of significant levels of motion. The other types of structures in the bay area not found in other areas are the port and harbor facilities. A cooperative effort with the Ports of San Francisco and Oakland should be conducted to provide a minimum level of instrumentation of some of these facilities. In addition, it is proposed that most of the dams in the area be instrumented with a minimum level of instrumentation that will provide some indication of the potential damage that they may experience in the event of a major earthquake.

APPENDIX E
CRITERIA FOR SELECTION AND INSTRUMENTATION OF BUILDING

This report presents recommended criteria to be applied to the selection of buildings for instrumentation and sets forth the factors used in development of the criteria. The report goes further to suggest a total number of buildings based on estimated resources expected to be available (Section 5). This basis for program planning has been rejected by the Board in favor of a plan based on the development of balanced program goals designed to secure the required data without regard to funding limitations. The criteria were otherwise accepted by the Board and included in the consideration of overall program plans. The Board, in concert with its Site Selection Committee, using the criteria provided in this report, has recommended to the Division of Mines and Geology that the instrumentation of 400 buildings will be adequate to provide a complete balanced program. This recommendation by the Board has been accepted by the Division of Mines and Geology and included in its program plan.

REPORT TO THE STRONG MOTION PROGRAM
ADVISORY BOARD
July 2, 1974
by
Sub-committee on Instrumentation for Structures
Christopher Rojahn, Chairman

CRITERIA FOR SELECTION AND INSTRUMENTATION OF BUILDINGS

Listed below are six (6) recommendations which establish the criteria for selecting and instrumenting buildings under the State of California Strong Motion Instrumentation Program. The recommendations were written by the Sub-committee on Instrumentation for Structures, an ad-hoc committee appointed by the Chairman of the Site Selection Committee on April 8, 1974.

As background information, it is important to point out that two committees—the Structural Engineers Association of Northern California Instrumentation Sub-committee and the Structural Engineers Association of Southern California Instrumentation Sub-committee—have already begun to actively, though informally, participate in the process of selecting buildings to be instrumented under the state program. Thus far, the committees have commenced on the initial vital function of mapping the locations of buildings in which upper story strong motion instruments have already been installed; they are also discussing the questions of which types of structures should be instrumented and how the selection process should be accomplished. The immediate establishment of formal criteria for selecting buildings would greatly facilitate their work.

RECOMMENDATIONS

1.* Eighty percent (80%) of all funds allocated for instrumentation of structures should be used to instrument buildings; the remaining twenty percent (20%) should be used to instrument other structures (such as dams or bridges).

Commentary: Because the source of all funds is building-permit receipts, it seems reasonable that 80% of the funds allocated for instrumentation of structures should be used to instrument buildings.

* Recommendation No. 1 was not considered by the Strong Motion Instrumentation Program Advisory Board or by the Division of Mines and Geology to be a valid factor in allocation for structural instrumentation. The determination was made that the only factor to be considered is the fulfillment of the requirement for engineering data.

2. The SEAOSC Instrumentation Committee should be requested to select buildings to be instrumented in the south half of the state whereas the SEAONC Instrumentation Committee should be requested to select buildings in the north half. The selection process should be based on the following criteria:

   (a) Approximately fifty percent (50%) of all available funds should be used to instrument buildings in the north half of the state (north of 37.2° N. latitude); the remainder should be used to instrument buildings in the south half (south of 37.2° N. latitude).

   Commentary: The fact that the south half of the state has potential of having the most seismic activity is counterbalanced by the fact that there are presently six (6) times as many buildings instrumented in the south than in the north. An allocation breakdown of fifty-fifty seems most equitable at this stage of program development.

   (b) With respect to geographic area, the buildings to be instrumented should be distributed as shown in Table E-1 and Figure E-1.

   Commentary: As recommended by the Site Selection Committee, the geographic distribution is based in general on the informal recommendations by R. B. Matthiesen and C. Rojahn. All sites are very close to or within Intensity Zone III as defined by the Preliminary Map of Maximum Expectable Earthquake Intensity, California Division of Mines and Geology, 1973[1]. The percentage of buildings to be instrumented in each area is based on the population density, the number of buildings in which strong motion instrumentation has already been installed, and a best-educated-guess approach relative to the amount and timeliness of potential future seismic activity.

   (c) With respect to building size and distance from the fault of interest, the distribution should be roughly as shown in Table E-2.

   Commentary: The matrix of Table E-2 is intended to be a guideline only. If the designated geographic area, as listed in Table E-1, does not contain a building of appropriate height, the building selection committee should select the most suitable substitute.

   (d) A large variety of standard types of buildings should be instrumented. An equitable distribution of the types given in Table E-3 would be ideal. All selected buildings should be typical and relatively simple in design.

   (e) Buildings designed prior to 1934 should not be instrumented.

   Commentary: The first State Acts specifying earthquake-resistant design were not passed until shortly after the Long Beach earthquake of March 10, 1933. Buildings built prior to that time are known to be potentially hazardous and therefore do not need instrumentation.

   (f) If an already instrumented building is selected for instrumentation, it should be re-instrumented in accordance with the guidelines stated herein.

   Commentary: Potential difficulties with respect to system operation, instrument and record ownership, and maintenance warrant such a policy.

   (g) Buildings selected should be those for which information concerning the structure, foundation, soils and geology is readily available.

3. Remote recording instrumentation, consisting of single or multi-axial accelerometers connected via data cable to a central recorder(s), should be used exclusively.

[1] Alfors, J. T., Burnett, J. L., Gay, T. E. Jr., 1973, Urban geology master plan for California: California Division of Mines and Geology Bulletin 198, p. 20.

Table E-1. Proposed geographic distribution of buildings to be instrumented under State program.

NORTH HALF OF STATE	
32%	Along the Hayward fault system as it extends from Milpitas to Geyserville
20%	Along the San Andreas fault as it extends from west of Los Gatos to west of Fort Bragg
16%	Along the Calaveras fault system as it extends from east of San Jose through Concord to east of Napa
8%	South Lake Tahoe
8%	Eureka and Ferndale
4%	Along the Midland fault system as it extends from Winters to Birds Landing
4%	Bishop
4%	Susanville
4%	Cedarville or Fort Bidwell

SOUTH HALF OF STATE	
20%	Greater Los Angeles area
16%	Along the San Jacinto fault as it extends from Cajon Pass to Hemet
16%	Along the San Jacinto fault as it extends from Hemet to El Centro
16%	Along the San Andreas fault as it extends from Cajon Pass to Calipatria
8%	Along the coast from Goleta to Oxnard
4%	Along the Calaveras fault system as it extends from east of San Jose through Hollister to the San Andreas fault
4%	Monterey
4%	Along the San Andreas fault as it extends from a few miles west of Los Gatos to Parkfield
4%	Along the San Andreas fault as it extends from Parkfield to Cajon Pass
4%	Along the Sierra Nevada fault as it extends from China Lake to Independence
4%	Barstow

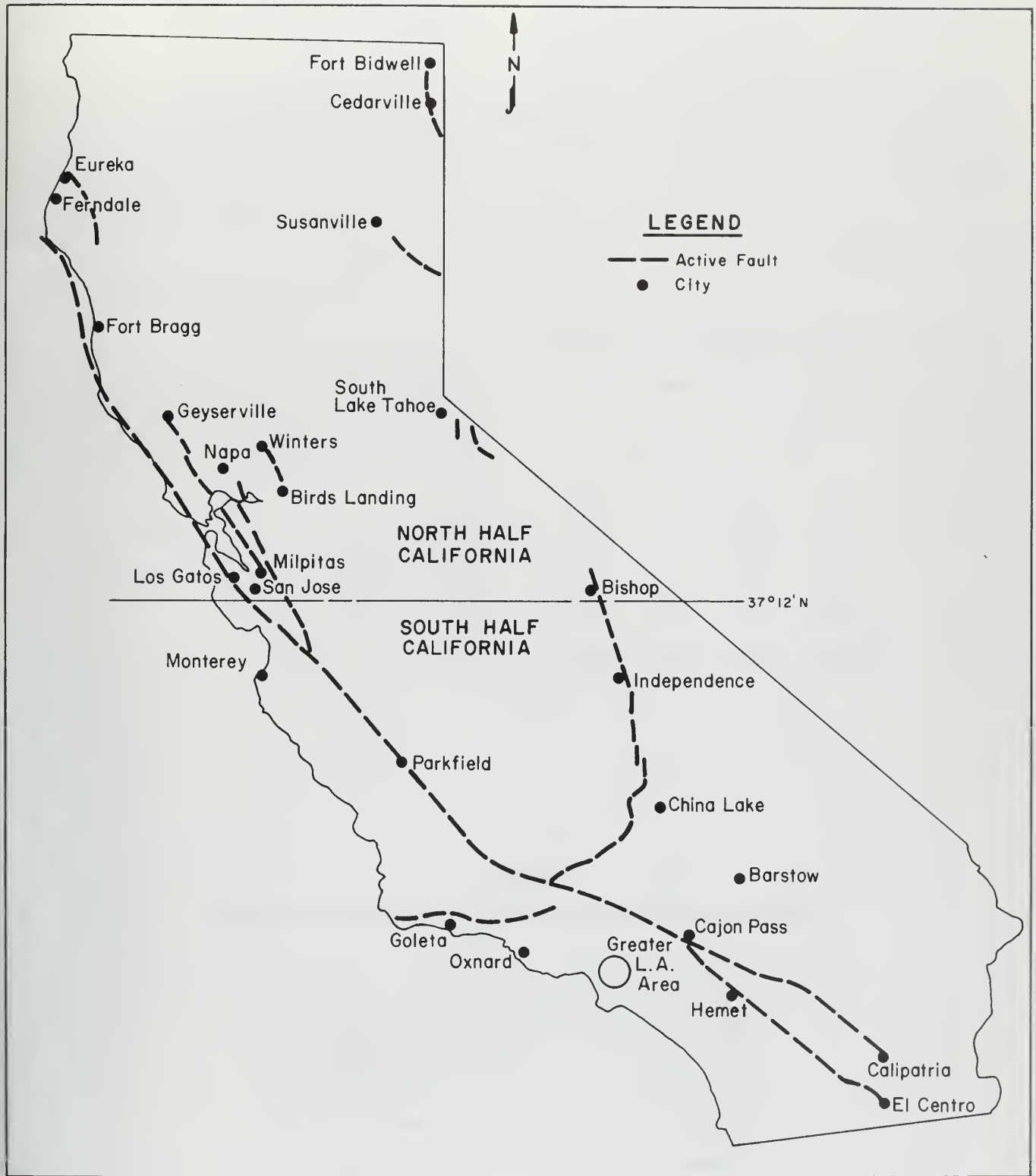


Figure E-1. Reference map for Table E-1.

Commentary: The advantages of remote recording equipment are significant: accelerometers can be attached to all necessary locations no matter how remote or inaccessible, their space requirements are minimal, and they are almost maintenance free; recorder(s) can be conveniently centrally located allowing easy maintenance and record retrieval. Hybrid systems composed of more than one type or brand of instrumentation (e.g. an SMA-1 or RFT-250 accelerograph used in conjunction with remote recording instrumentation) should not be used in any of the buildings; it is felt that the different operating characteristics in such systems would adversely affect the quality and consistency of data.

4. All buildings should be instrumented in accordance with the guidelines and specifications developed by Seismic Engineering, U.S.G.S.

5. Based on current budget estimates and current instrumentation costs (minimum of $6,000 per building), each building selection committee should submit to the Site Selection Committee as soon as possible a list of twenty-five (25) buildings to be instrumented (in order of priority). Similar lists should be submitted annually to the Site Selection Committee until five hundred (500) buildings have been instrumented under the state program.

6. The state should provide man-power to do the following: obtain necessary permission to instrument each selected building; obtain structural plans for each building; prepare site description (soil characteristics and geology); and install all instrumentation. Seismic Engineering, U.S.G.S., should be requested to carry out the task of precisely pinpointing on the structural plans all locations at which instrumentation is to be installed in each building.

Table E-2. Proposed distribution of instrumented buildings as a function of distance from fault of interest.

Distance from fault (miles)	Number of stories			
	1-2	3-6	7-15	16+
0-2	20%	16%	4%	none
2-5	12%	16%	8%	4%
5-10	none	none	12%	8%
10+	none	none	none	none

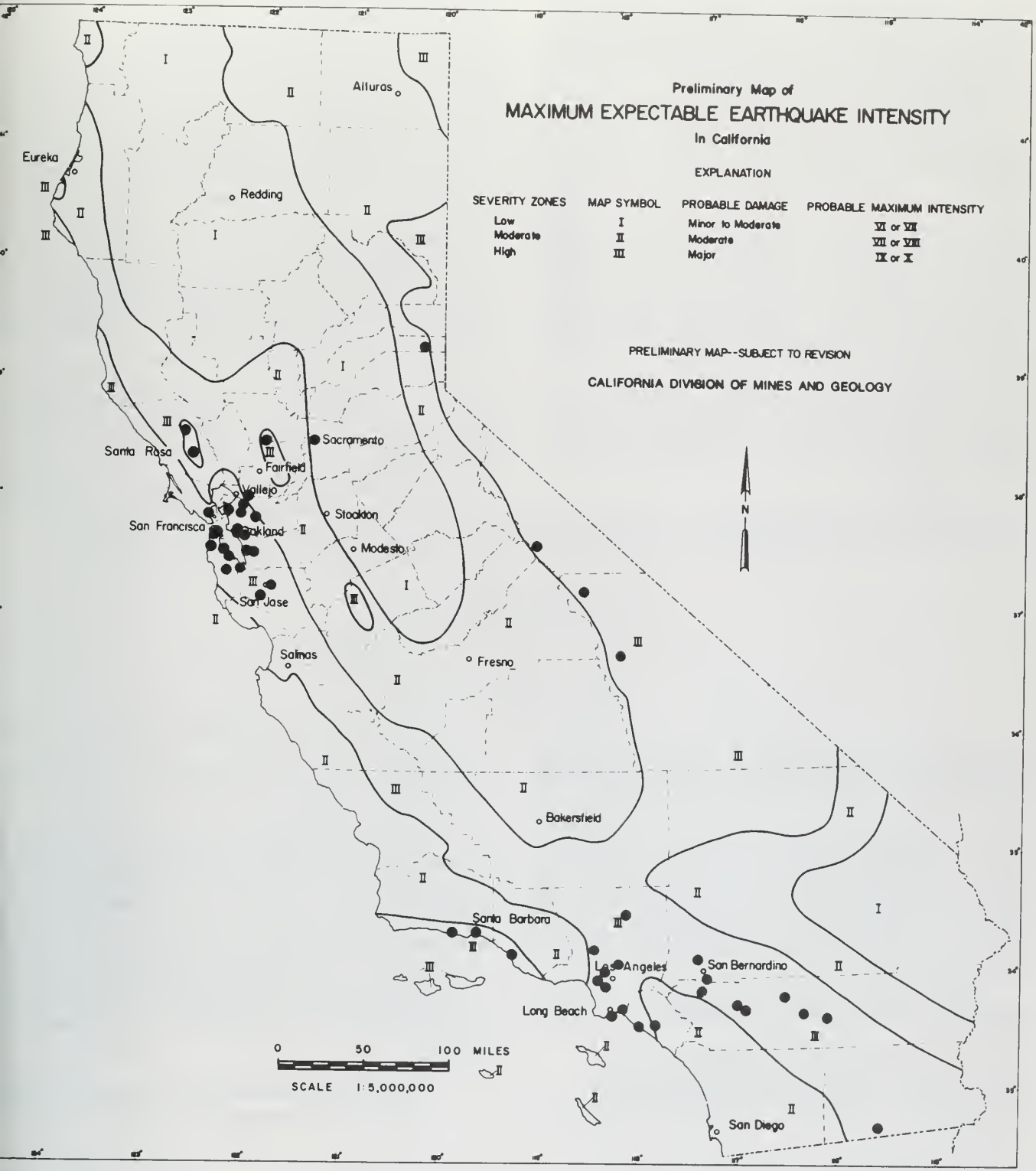
Table E-3. Types of buildings to be instrumented.

ONE- AND TWO-STORY BUILDINGS
Open frame (gyms, auditoriums, etc.)
Continuous frame (classrooms, offices, etc.)
Box structures (commercial masonry or concrete wall structures with flexible diaphragms)
Combination (parking structures, shopping plazas)
BUILDINGS NOT OVER SIX STORIES
Frame
Shearwall
Combination
Precast structural elements
BUILDINGS OVER SIX STORIES
Frame
Shearwall
Combination

APPENDIX F

BUILDING INSTRUMENTATION RECOMMENDATION

The following tables were submitted by the Subcommittee on Instrumentation of Structures to the Site Selection Committee, Strong Motion Instrumentation Program Advisory Board. The Board and the Division accepted the total recommendation of 41 buildings and 12 alternates conditionally, with final decision and selection of buildings to be based on operational feasibility (permission from owner, difficulty in executing installations, etc.). Such final decision is placed in the hands of a site review group consisting of a representative of the Division of Mines and Geology, with authority to make the final decision, with support from a coordinating representative from the U. S. Geological Survey, advisory representatives from the engineering profession, and representatives from the building designer and owner.



gure F-1. Locations (●) of recommended buildings (including those already approved by the Site Selection Committee).

APPENDIX G
RECOMMENDATION FOR INSTRUMENTATION OF UTILITY STRUCTURES

Following is a report by the California Power and Water Earthquake Engineering Forum (CPWEEF) to the California Strong Motion Instrumentation Program Advisory Board recommending the instrumentation of 90 utility structures with 244 accelerographs.

This report was submitted to the Board in response to a request for such a recommendation by letter from Dr. C. Martin Duke, a Board representative, to Mr. Laurence B. James, Forum Representative. An excerpt from the letter follows:

"In behalf of my Committee, I would like to ask the California Water and Power Earthquake Engineering Forum if it would undertake to help in this planning effort. Specifically, would the Forum be willing and able to develop an estimate of how many of the State's accelerographs should be installed in, on and around water and power facilities? We have tentatively in mind that 100 to 300 instruments might be justified.

"Subsequently, would the forum be able to develop detailed suggestions as to the locations of instruments? (Formal recommendations of specific locations are the concern of the Site Selection Committee of the Board, Chaired by Gordon Oakeshott.)"

The CPWEEF is an organization of representatives of a number of water and electric companies, and county, state and federal agencies, a list of which is given in the report as the agencies represented by ad hoc committee members. This forum was formed with the objective of "attainment of earthquake resistant water supply and power project facilities in order to minimize economic loss and public imperilment. This Forum will seek this primary objective by exchanging information on earthquake engineering subjects related to water and hydroelectric power projects; establishing liaison among water and power agencies at the technical management level; inviting critical, open, and candid discussion of mutual problems; identifying needs for and encouraging research, training, and practical application of the technology that is being developed; establishing common guidelines for design and operating criteria; encouraging joint sponsorship of research and practical projects of mutual interest; and identifying definitions and criteria common to water and power interests and encouraging their use."

The CSMIP Advisory Board selected the Forum as a source for input into the development of work-plan 2 because of its broad area of representation, experience in developing such information, and interest in the strong motion program and its application to the specific study of utility facilities.

The report has been favorably received by the Advisory Board and its Site Selection Committee, but as of this writing, the report has not received formal acceptance.

Report on Recommended Locations of Strong Motion Instruments On and Around Water and Power Facilities by California Water and Power Earthquake Engineering Forum

Extracted from a letter from C. J. Cortright, California Department of Water Resources, to Dr. C. Martin Duke, CSMIP Advisory Board representative, dated September 29, 1975:

The Forum, by unanimous agreement, fully endorses the State's SMI Program. The Forum feels that efforts required by the agencies who participate in the program will be more than offset by the valuable information to be received during future earthquakes. It was agreed that the information would not only be a valuable tool in the understanding of seismic response of structures by the professions but would also benefit the agencies.

To accomplish the task that you requested, the Forum appointed an ad-hoc committee, comprised of the following individuals:

Julian L. Bardoff, San Francisco Water Department
John C. Burton, San Diego Gas & Electric Company
David J. Dayton, East Bay Municipal Utility District
Michael Johnson, Los Angeles County Flood Control District
Art Tessen, Los Angeles Department of Water and Power
H. John Hovland, Pacific Gas & Electric Company
Paul W. Morrison, Jr., California Department of Water Resources
Dennis K. Ostrom, Chairman, Southern California Water Edison Company
Arthur I. Rezin, Metropolitan Water District of Southern California
J. Lawrence Von Thun, Bureau of Reclamation, U.S. Department of the Interior

The ad-hoc committee first met in Los Angeles on December 19, 1974. At this time, each agency presented its seismic instrumentation program. Each agency was asked to submit a list of currently planned and suggested locations for future strong motion instrumentation. From this list and the judgment of the members of the committee, a determination was made of the most appropriate agency plants or installations where instruments could be located. A major consideration that was used in this selection was to maximize the learning from the instrumentation in future strong earthquakes.

The general locations decided upon by the committee for evaluation for strong motion instrumentation included:

Steam power plants
Substations
Dams
Storage tanks
Geothermal plants
Pumping plants
Tunnels
Pressure control stations
Treatment plants
Pipelines
Towers
Underground storage

Each of the above locations was discussed and evaluated in terms of the following specific considerations:

. Availability of existing structural data necessary for making an analysis.
. Availability of modern methods of dynamic analysis that can be applied to the installation.
. Learning quotient from recordings in terms of design changes.
. Susceptibility of structure types to failure.
. Loss of life potential should the structure fail.
. Property damage potential should the structure fail.
. Public activity disruption potential should the structure fail.

A priority matrix was then developed (Figure G-1).

The ad-hoc committee met again on Thursday, March 0, 1975, at the SCE main office in Rosemead.

Several of the agencies already have seismic surveillance systems in operation. An inventory of the existing strong motion instrumentation (accelerographs) is presented in Table G-1.

Each agency recommended the number of locations and instruments for installation at its facilities as shown below and in Table G-2.

Agency	Locations	Instruments
SCE	8	24
DWP	7	15
LACFCD	12	36
SDGE	2	4
SFWD	3	9
PG&E	24	50
MWD	10	24
DWR	8	22
EBMUD	23	60
Subtotal	90	244

Figure G-1. Priority matrix to be used to determine generally the facility types to be instrumented. Each factor was weighted from 1 (highest) to 3 (lowest) to indicate data-producing potential.

Facility type	*Site data*	*Method*	*Learning*	*Susceptibility*	*Loss of life*	*Property loss (private)*	*Disruption of activities*	*TOTAL*	*Matrix priorities*
Steam plant	3	1	3	2	1	1	2	13	5
Substation (large)	2	2	3	3	1	1	2	14	4
Dams	3	2	3	2	3	3	3	19	1
Storage tanks	2	1	3	2	2	1	1	12	6
Geothermal plant	3	1	3	1	1	1	1	11	7
Pumping plant	3	2	2	1	1	2	2	13	5
Tunnels	1	1	3	2	1	1	2	11	7
Pressure control station	3	1	3	1	1	1	2	12	6
Treatment plant	3	2	2	2	1	2	3	15	3
Pipeline	1	1	1	3	1	1	2	10	8
Towers--reservoir	2	2	3	3	1	1	1	13	5
Underground storage--gas	3	2	3	3	1	1	3	16	2

Table G-1. Existing seismic instrumentation locations owned by members of the California Water and Power Earthquake Engineering Forum.

SOUTHERN CALIFORNIA EDISON COMPANY (SCE)

Rush Substation
Goleta Substation
Huntington Beach Generating Station
Lighthipe Substation
Lugo Substation
Mira Loma Substation
Olinda Substation
Ormond Beach Generating Station
Pardee Substation
Redondo Beach Generating Station
Vincent Substation
Eldorado Substation
Villa Park Substation
Magunden Substation
Devers Substation
Rio Hondo Substation
Bailey Substation
Santa Clara Substation
San Onofre Generating Station
Vidal Proposed Generating Station
Lucerne Proposed Generating Station

LOS ANGELES DEPARTMENT OF WATER AND POWER (LADWP)

Bouquet Canyon Reservoir
Encino Reservoir
Lower Stone Canyon Reservoir
Victorville Switch Substation
Haynes Substation
Sylmar D.C. Converter Station
Control Gage Power Plant
San Joaquin Generating Station
Station B Substation
Station E Substation
Station G Substation
Station Q Substation
Scattergood Generating Station
Castaic Power Plant
Los Angeles Reservoir

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT (LACFCD)

Pacoima Dam
Santa Ana Dam

SAN DIEGO GAS AND ELECTRIC COMPANY (SDGE)

Electric Building

SAN FRANCISCO WATER DEPARTMENT (SFWD)

PACIFIC GAS AND ELECTRIC COMPANY (PG&E)

Mendocino Proposed Generation Station
Humboldt Bay Generation Station
Diablo Canyon Generation Station
Scott Dam

METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA (MWD)

Jensen Treatment Plant
R.B. Dremer Filtration Plant
F.E. Weymouth Filtration Plant
Gene Pumping Plant
Iron Mountain Pumping Plant
Julian Hinds Pumping Plant
Copper Basin Dam
Lake Mathews
Merris Dam
Garvey Reservoir
Palos Verdes Reservoir
Orange County Reservoir
Live Oak Reservoir
Skinner Dam
Sepulveda Dam Control Structure
Headquarters Building Annex

CALIFORNIA DEPARTMENT OF WATER RESOURCES (DWR)

Castaic Dam
Cedar Springs Dam
Cedar Springs (Miller Guard Station)
Del Valle Dam
Oroville Dam
Oroville Seismograph Station
Pyramid Dam
Perris Dam
San Luis Dam
Dos Rios (damsite under investigation)
Newville (damsite under investigation)
Frenchman Reservoir
Devil Canyon Power Plant
Buena Vista Pumping Plant
Delta Pumping Plant
Dos Amigos Pumping Plant
A. D. Edmonston Pumping Plant
Oso Pumping Plant
Pearblossom Pumping Plant
San Luis Dam Pumping and Generating Plant
Wheeler Ridge Pumping Plant
Wind Gap Pumping Plant
Castaic Intake Tower
San Bernardino Intake Tower
Peripheral Canal
Apeel Array
Buena Vista Array
Cholame Array
Lake Hughes San Andreas Fault Array
Orestimba (free field)
South Bay Aqueduct
(Santa Clara Terminal Facilities)

EAST BAY MUNICIPAL UTILITY DISRICT (EBMUD)

Briones

U.S. BUREAU OF RECLAMATION (USBR)

Stampede Dam
Auburn Dam
Casitas Dam
Cachuma Dam
Boca Dam, Planned
Monticello Dam, Planned

U.S. DEPARTMENT OF THE ARMY, SOUTH PACIFIC DIVISION, CORPS OF ENGINEERS (ACE)

Butler Valley
Coyote Dam
Warm Springs Dam
Fruitvale Avenue Bridge
Black Butte Dam
Martis Creek Dam
New Hogan Dam
Pine Flat Dam
Terminus Dam
Isabella Dam
Brea Dam
Mojave Dam
Prado Dam
Salinas Dam
San Antonio Dam
Sepulveda Dam
Whittier Narrows Dam

Table G-2. Proposed seismic instrumentation locations owned by members of the California Water and Power Earthquake Engineering Forum.

SOUTHERN CALIFORNIA EDISON COMPANY (SCE)

Mono Geothermal Power Plant
Etiwanda Steam Power Plant
Ormond Beach Steam Power Plant
Huntington Beach Steam Power Plant
Redondo Steam Power Plant
Gem Lake Dam
Vermilion Valley Dam
Shaver Lake Dam

LOS ANGELES DEPARTMENT OF WATER AND POWER (LADWP)

Haynes Steam Power Plant
Valley Steam Power Plant
Castaic Surge Chamber
R.S.H. Hollywood Substation
R.S.D. 5956 Venice Boulevard Substation
R.S.F. East Los Angeles Substation
R.S.J. Northridge Substation

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT (LACFCD)

Big Tujunga Dam
Devil's Gate Dam
Eaton Wash Dam
Santa Anita Dam
Sawpit Dam
San Gabriel Dam
Big Dalton Dam
San Dimas Dam
Live Oak Dam
Thompson Creek Dam
Puddingstone Dam
Sierra Madre Dam

SAN DIEGO GAS AND ELECTRIC COMPANY (SDGE)

South Bay Steam Power Plant
Encina Steam Power Plant

SAN FRANCISCO WATER DEPARTMENT (SFWD)

San Andreas Dam
Calaveras Dam
O'Shaughnessy Dam

PACIFIC GAS AND ELECTRIC COMPANY (PG&E)

Salt Springs Dam
Spaulding #1 Dam
Almanor Dam
Van Nordon Dam
Pittsburg Steam Power Plant
Moss Landing Steam Power Plant
Ulton Substation
McDonald Island
Geysers Geothermal Power Plant
Haas Power House
Newark Substation
Vaca Dixon Substation
Metcalf Substation
Tesla Substation
Tionesta Gas Compr.
Midway Substation
Morro Bay Steam Power Plant
Gates Substation
Martin Substation
Pit #1 Power House
Kern Canyon Power House
Contra Costa Steam Power Plant
Bolinas Substation
Fremont Substation

METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA (MWD)

Lake Mathews Dike No. 1 Dam
Palos Verdes Reservoir Dam
Garvey Reservoir Dam
Morris Dam
Gene Wash Dam
F.E. Weymouth Filtration Plant
Sepulveda Canyon Control Facility
West Orange County Feeder Pressure Control Structure
Coastal Junction Pressure Control Structure
West Portal of San Jacinto Tunnel

CALIFORNIA DEPARTMENT OF WATER RESOURCES (DWR)

Frenchman Dam (additional seismograph)
Devil Canyon Power Plant
A.D. Edmonston Pumping Plant
A.D. Edmonston Switchyard
Pearblossom Pumping Plant
Santa Ana Pipeline
Angeles Tunnel
Canal Check Structure (3.5 miles northeast of City of Maricopa)

EAST BAY MUNICIPAL UTILITY DISTRICT (EBMUD)

San Pablo Dam
Chabot Dam
Upper San Leandro Dam
Lafayette Dam
Dunsmuir Dam
North Dam
Berryman Dam
South Dam
Danville Dam
Central Dam
Camanche Dam
Pardee Dam
Maymud Water Pollution Control Plant
Mokelumne #3 Aqueduct
Mokelumne Aqueducts
Amito Reservoir Concrete Tank
Amador Reservoir Steel Tank
Richmond Reservoir Concrete Tank
Walnut Creek #3 Pumping Plant
Upper San Leandro Filter Plant
Walnut Creek Filter Plant
Pearl Reservoir Steel Tank
Field Reservoir Concrete Tank

Table G-3. Summaries of proposed seismic instrumentation locations in Table G-2.

Agency and type of installation	*Number of installations*	*Total instruments*
SOUTHERN CALIFORNIA EDISON COMPANY		
Steam plant	4	13
Dam	3	10
Geothermal plant	1	1
LOS ANGELES DEPARTMENT OF WATER AND POWER		
Steam plant	2	8
Substation	4	4
Dam	2	3
LOS ANGELES COUNTY FLOOD CONTROL DISTRICT		
Dam	12	36
SAN DIEGO GAS AND ELECTRIC COMPANY		
Steam plant	2	4
SAN FRANCISCO WATER DEPARTMENT		
Dam	3	9
PACIFIC GAS AND ELECTRIC COMPANY		
Steam plant	5	15
Substation	10	14
Dam	4	12
Geothermal plant	1	4
Pumping plant	3	4
Pressure control station	1	1
METROPOLITAN WATER DISTRICT OF SO. CALIF.		
Dam	5	14
Storage tank	1	3
Pressure control station	3	5
Water treatment plant	1	2
EAST BAY MUNICIPAL UTILITY DISTRICT		
Dam	12	32
Storage tank	5	11
Pumping plant	1	3
Water treatment plant	3	7
Pipeline	2	7
CALIFORNIA DEPARTMENT OF WATER RESOURCES		
Dam	1	3
Pumping plant	2	6
Tunnel	1	3
Pipeline	1	2
Canal check structures	1	2
Hydro plants	1	2
Switchyard	1	4
	97	244

Type of installation	*Number of installations*	*Number of instruments*
Steam plant	13	40
Substation	14	18
Dam	40	116
Storage tank	6	14
Geothermal plant	2	5
Pumping plant	4	7
Tunnel	0	0
Pressure control station	6	9
Water treatment plant	4	9
Pipeline	2	7
Tower-reservoir	0	0
Underground storage--gas	0	0
Canal check structures	1	2
Hydro plants	1	2
Switchyard	1	4
	97	244

Each agency has provided the following information for each recommended site:

1. Name of site.
2. Type of structure on which instrument(s) is located.
3. Coordinates of site.
4. Approximate location.
5. Structural features.
6. Capacity characteristics.
7. Geology.
8. Seismology.
9. Distance from active faults.
10. Foundation type.
11. Age of structure(s).
12. Matrix priority - See Figure G-1.
13. General priority.

A map showing the approximate location of all facilities and the information listed above is on file at the Division of Mines and Geology headquarters office.

The general priority is based on each agency representative's judgment considering: agency's priority, decision matrix priority, over-all program objectives, and ad-hoc group discussion of March 20, 1975, at SCE. Therefore, the matrix priority represents a committee judgment as to which types of installations will provide the most meaningful data, and the general priority represents the judgment of an individual (there were different individuals for each agency) regarding his agency's installations. The Forum recommends the use of the general priority in the selection of instrumentation sites.

The above information on each agency's selected locations is submitted according to DWR format by agency as separate attachments. Additional pertinent information (e.g., number of instruments, their locations, and information to be gained) about the site is available on request. Generally, and in all cases where the agency thought it appropriate, a free field instrument is proposed for each installation.

Existing (Table G-1) and proposed (Table G-2) instrumentation was plotted on maps of California and it was found that the instruments are located predominantly in populated areas. Each location is identified by a Roman numeral and an Arabic numeral. There are cases where additional instrumentation is being recommended by the California Department of Water Resources for sites, some of which are owned by agencies not represented on the CWPEEF.

Certain concerns have surfaced during the Forum's consideration of strong motion instrument locations. The Forum feels a need to reconcile these concerns prior to the installation of any instruments. Guidance by the CSMIP Advisory Board on these matters, perhaps in the form of a written specification or guide, would serve to dispel most concerns. The three major concerns are:

1. Will the maintenance program required for such an ambitious undertaking be realized?
2. How will the data be handled after a seismic event?
3. Will a usable interpretation of all the recorded data be realized?

The Forum believes that the following comments may be helpful to the Board in considering these concerns:

1. Upon the selection of an instrument location by the Site Selection Committee, the Board's staff and Operating Agency will discuss the maintenance program. The option would be open to the Operating Agency to maintain the instruments located on its facilities. The Operating Agency's maintenance program must meet or exceed the Board's standards.

2. At the same time, the Board's staff and Operating Agency will discuss the timeliness and logistics of data collection. The option would be open to the Operating Agency to collect the data from the instruments in its facilities while meeting or exceeding the U. S. Geological Survey informal standards of data retrieval. In any case, the Operating Agency will receive data from their installations prior to public release.

3. At the same time, the Board's staff and Operating Agency will discuss the initial interpretation of the data, the reporting format, and the timeliness of the release of data. The option would be open to the Operating Agency to perform this initial data processing, interpretation, and reporting while meeting or exceeding the Board's standards.